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FINAL REPORT FOR RESEARCH AGREEMENT
#INT-96092-RJVA
"Hydrology and Water Management for Prescribed Burning in Pond Pine Woods"
NORTH CAROLINA STATE UNIVERSITY
FS Contact: Mr. Roger D. Hungerford
Mr. Kevin C. Ryan
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Hydrology and Water Management

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on the U. S. Air Force Dare County Range

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Hydrology and Water Management for Prescribed Burning in Pond Pine Woods on the U.S. Air Force Dare County Range

James D. Gregory
Department of Forestry
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Final Project Report
Research Joint Venture Agreement No. INT-96092-RJVA
USDA Forest Service
Rocky Mountain Research Station

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INTRODUCTION

Fire is a key ecological process in the pond pine woods ecosystem that occurs on the organic flat wetlands in the eastern Coastal Plain of the Southeast. Pond pine (*Pinus serotina*) and many of the associated tree and shrub species in the forest type are fire-adapted species that owe their persistence, in part, to adaptation to frequent fire in the natural environment. Variations in community structure and the dominant tree and shrub species in the complex mosaics of vegetative communities on organic soils are related to both soil variation and fire history. Wild fires in these plant communities are very intense and unpredictable. The intensity of a fire and the viable seeds and live rootstocks that remain following a fire influence the post-fire successional vegetation. In the prolonged absence of fire, pond pine woods communities will succeed to bay forest communities dominated by loblolly bay (*Gordonia lasianthus*), sweetbay (*Magnolia virginiana*) and red bay (*Persea palustris*) (Schafale and Weakley, 1990; Sharitz and Gibbons, 1982).

The succession from pond pine woods to bay forest that results from fire exclusion has become a critical ecological issue on the U.S. Air Force Dare County Range (DCR). The goal of fire management on the DCR since its inception has been immediate suppression of any fire that occurs on or near the impact zones due to two important factors. Firstly, adjacent to the impact zones are many square miles of tall and short pocosin communities on deep organic soils that provide a huge fuel source and an area for build-up of great intensity of a wildfire. Secondly, the practice bombs and tracer bullets used in aerial gunnery practice on the impact zones provide a ready, year-round ignition source. The policy of fire suppression and exclusion has resulted in the development of a midstory of bays with red maple (*Acer rubrum*) and other species in stands of pond pine on shallow organic soils located to the north of the Air Force impact zone. A number of groups of red-cockaded woodpeckers (*Picoides borealis*) occur in those stands. Managing the habitat to optimize conditions for the woodpeckers will require removal of the mid-story to restore the pond pine stands to the open condition that likely existed when the woodpecker population became established (U.S. Fish and Wildlife Service, 1988). Prescribed burning is the only cost-effective method to effect control of that midstory.

Prescribed burning is an important tool for managing the pond pine woods forest type whether for timber production, wildlife habitat enhancement or simple preservation of that particular community. However, because of the difficulty of controlling fire in pond pine and shrub communities on organic soils, prescribed fire has not been used in established stands. Critical to the effective use of prescribed fire in forest communities on organic soils is understanding of the relationships of fuel, soil moisture, and weather to fire behavior. Pond pine communities occur on wetlands where natural fires occur during dry periods when the water table is well below the surface. Fires do not readily ignite and spread when the water table is at or close to the surface and are even difficult to ignite and maintain under low water table conditions during late evening and early morning when the relative humidity is high. A standard practice for bringing wildfire on organic soils under control is to pump water into a burning area to raise the water table and extinguish the surface and ground fire. Therefore, water management and control of the water table level is essential to the conduct of an effective but controllable prescribed burn. Having some control over the water table level and the resultant moisture content of the organic soil and

ground level fuel will provide some control over the intensity of a fire and the extent of consumption of the ground level fuel and the organic soil.

Safely and effectively conducting prescribed burning in the pond pine forests on organic soils on the DCR will require information on the water table hydroperiod and the relationship of water table level to soil moisture and fuel moisture. Information is also needed on the volumes of water needed to change the water table level, and the feasibility of moving and storing water in the ditches of a typical roaded wetland forest. Also needed are an understanding of subsurface flow rates through soils and roads and the water storage and movement characteristics of roadside and lateral ditches. Understanding the basic hydrologic character of the range ecosystems is the first step in developing the comprehensive water management practices needed.

Fire management will involve water management to accomplish two objectives:

- Establish conditions for a controllable but effective burn in a specific area while, in the surrounding area, ignition and spread potential are low enough to control ignition from spotting.

- Rapidly raise the water table in the burned area to mop up the fire and prevent continuing ground fire.

The first objective involves understanding the hydrology of the area in question, in particular, the variation of the water table depth and rate of water table decline under differing weather conditions. The second objective involves ample water storage close to the area in question and the ability to rapidly transfer large volumes of water into the burn area. This report describes the results of preliminary research during 1997 at the Dare County Range to address these questions.

OBJECTIVES

The purpose of this research was to address the specific hydrologic and water management questions related to conducting prescribed burning in the pond pine woods forest type on the Dare County Range. Specific objectives were to:

1. Establish a climate station at the Dare County Range headquarters to collect data on rainfall and other meteorological variables needed for hydrologic and fire behavior analyses.

2. Design and oversee construction of a ditch system, including water control structures, needed to manipulate water levels on the paired watersheds.

3. Determine the water table hydroperiod in a network of water table wells on the two paired watersheds of the pond pine woods ecosystem and the effects of weather and site variables. Determine the relationship of water table level to soil moisture and ground level fuel moisture.

4. Determine the character and hydraulic conductivity of the upper 3-5 m of the soil and determine the rates of near surface ground water movement through the soil and roads.

5. Conduct pumping tests to determine the feasibility of water management strategies and the effects of water movement and storage on the water table level and soil moisture and ground level fuel moisture.

METHODS

RESEARCH APPROACH

This study was designed to provide information about the hydrologic character of the DCR at two scales: (1) the entire range and (2) two small blocks that would be feasible as areas for conducting prescribed burns.

The range property constitutes a major portion of the southern end of the Dare County mainland peninsula. Information on the ecological character of the range was gathered through several different sources:

1. Published sources, including
   A. Dare County Soil Survey (Tant, 1992)
   B. USGS 7.5 minute series topographic maps
   C. Ecosystem Survey of Dare County Air Force Range North Carolina (NCDEHNR, 1995)
2. Information provided by staff of the DCR – maps, land management history, anecdotal information on hydrologic events, etc.
3. Intensive reconnaissance of the DCR

Information on topography, soils, climate, the road and ditch system, water management practices, etc. was gathered to provide insight on the general hydrologic character of the DCR.

The small-scale, detailed study of the hydrologic character of small blocks used the paired watershed approach. Two pond pine stands located to the north of the Air Force impact area that are surrounded by roads and that have ditches on three sides were selected as the study blocks. An intensive study of the spatial and temporal variation of the water table and the influence of potential evapotranspiration, rainfall, and soils factors was conducted.

SITE DESCRIPTION – THE DARE COUNTY RANGE

Topography

The Dare County mainland is a low flat peninsula on which most of the surface probably lies at or below 1.5 m MSL. The USGS 7.5 minute topographic maps for the area with a contour interval of 5 ft (1.52 m) have no contour lines. A few bench marks on US Highway 264 are noted at 6 ft on the maps but the road surface is elevated above the surrounding terrain. The stream network and the spatial distribution of soil associations indicate that the highest elevations are found near the center of the peninsula and there may be some small areas with elevations at or slightly above 1.5 m.

Relief on the peninsula exists at three scales, regional, local, and micro. Regional relief over distances of several kilometres of up to 0.5 m per km (0.05%) likely occurs in the terrain on the

western side of the peninsula, particularly in the drainage basins of the two largest streams, Whipping Creek and Milltail Creek. In that region, the "ridges" of Hyde soils are frequently located only 1-2 km from the stream channels. However, no streams exist on the eastern side of the peninsula and relief is quite low. Local relief of about 0.3 m occurs over distances of several hundred to more than a thousand metres in both the soil surface (organic surface) and the surface of the mineral soil (C horizon) beneath the organic layer. The relief at the soil surface is likely due to the undulation of the mineral soil surface as well as variability in the thickness of the organic layer. As will be noted later in the report, this local relief apparently has less effect on the water table than the much greater micro relief but does contribute to random variability in water table depth. Microtopography with relief of 0.4 – 1.0 m or more over distances of several metres is common throughout the various vegetation communities on organic soils. Hummocks of fibrous peat built up around trees or large shrubs are separated by depressions with a relatively thin fibrous layer over muck.

Geology

The surficial geologic substrate of the Dare County mainland consists of marine sediments that were deposited during the late Pleistocene in sound, estuarine, or near shore environments. Dare County lies within the Albemarle embayment, a zone of structural downwarping that occupies most of northeastern North Carolina. A series of five sea level transgressions/regressions during the Pleistocene (0.01 to 1.6 million years ago) resulted in a complex series of sedimentary layers. Detailed stratigraphy of Dare County is not available, however, the formations of the Albemarle embayment have been described (Ward, et al., 1991). The major near surface formation is the James River formation which is composed of very shelly sands. Overlying that layer are the loamy to clayey sediments that comprise the C horizons of the soils.

The character of the sediments at the surface indicates that the area has remained at a relatively low elevation with the water table near the surface since the sediments were deposited. Soil forming processes have operated to develop mineral soil horizons only on the relatively small areas of higher elevation in the north-central portion of the peninsula (Hyde, Cape Fear and Roper soil series). The Cg horizon of the Hyde-Cape Fear Association and the mineral sediment (Cg horizon) underlying the great expanses of organic soils have massive structure and relatively fine texture, ranging from loamy sand to clay, but predominately loamy to clayey. The mineral sediments are gleyed (as shown by the "g" suffix on the horizon symbol), indicating that significant ferrous iron is present and the soils are permanently reduced (Daniels, et al., 1984; Tant, 1992).

Formation of the organic surface that covers much of the Dare County peninsula has resulted from a different set of hydrologic conditions than is common for the broad organic flats (pocosins) in other counties of the lower Coastal Plain. Development of the large organic flats throughout the outer Coastal Plain began about 10,000-12,000 years ago with blockage of many stream systems. At that time, sea level was about 25 m below the current level. The combination of blocked runoff and restrictive soil layers began peat development which then became self-propagating (Otte, 1982). Pocosins, such as those in the Pocosin Lakes National Wildlife Refuge (Hyde, Tyrrell and Washington Counties), the Croatan National Forest (Craven County) and the Hofmann Forest (Jones and Onslow Counties) formed on broad, flat interstream divides where vertical drainage was limited by restrictive sediment layers. In such wetland

systems, the deepest organic soils are located at the greatest distances from streams and moderately well-drained to well-drained soils are located near major streams.

On the Dare County peninsula, sea level has been a major hydrologic control and the spatial distribution pattern of the organic surface is opposite that of the pocosins that are located at higher elevations (5-20 m). In Dare County, the highest surface elevations have no organic cap on the mineral soil and the deepest portions of the organic surface are located in the drowned stream valleys. Deep peats surround the Alligator River and its tributaries, and as noted above, occupy a topographic gradient to the stream channels. A large pocosin with relatively deep peat on the southeastern portion of the peninsula formed over flats or broad depressions at very low elevation. There is a large Carolina bay buried in peat in that region and Stumpy Point bay is considered by geologists to be a Carolina bay that has been encroached upon by Pamlico Sound (Ingram, 1982; Otte and Ingram, 1980; Otte, 1982).

Soils

Disregarding the narrow fringe of marshes on the sound border of the peninsula, the Dare County mainland has a very simple suite of soils (Table 1). The sedimentary parent materials are similar throughout the peninsula, so the only variant is the degree of wetness and the resultant depth of the organic surface. All soil series are very poorly drained and range in surface character from black loam at the highest elevations to muck >130 cm deep at the lowest elevations. The Pungo muck along the Alligator River and in the stream valleys ranges up to 5 m deep (Otte and Ingram, 1980). The depth ranges shown in parenthesis for the three Histosols indicate the standard organic depth ranges for the two subgroups used in the U.S. Soil Classification. However, because of local relief, small areas of lesser or greater organic depth than that specified for a mapping unit can be found.

Table 1: Soil series on the Dare County mainland.

Series	Surface Horizon: Texture, Ave. Depth, cm	Classification
Hyde loam	A1: black loam, 18 A2: dark gray loam, 18-33	Fine-silty, mixed, thermic Typic Umbraquults
Cape Fear loam	A: black loam, 33	Clayey, mixed, thermic Typic Umbraquults
Roper muck	Oa: black muck, 33	Fine-silty, mixed, acid thermic Histic Humaquepts
Ponzer muck	Oa: black to dark brown muck, 61 (40-130)	Loamy, mixed, dysic, thermic Terric Medisaprists
Belhaven muck	Oa: black to dark brown muck, 97 (40-130)	Loamy, mixed, dysic, thermic Terric Medisaprists
Pungo muck	Oa: black to dark brown muck, 165 (>130)	Dysic, thermic Typic Medisaprists

Climate

The climate of the Dare County mainland reflects the maritime influences of its coastal location. The average temperature for 1966-1990 at the Manteo Airport was 62° F with an average daily minimum of 34.7° F in January and an average daily maximum of 87.3° F in July. Rainfall normals for the same period show that rainfall is well distributed throughout the year. The normal annual rainfall was 52.38 in. The monthly low of 3.45 in occurred in April and the monthly high of 5.79 in occurred in August (Table 2). The temporal pattern of average daily maximum temperature is also indicative of the pattern of potential evapotranspiration (PET). The highest rates of PET occur in the months of June, July, and August and the lowest rates in December, January and February.

Hydrology

With the exception of a few very small sand ridges, the entire Dare County mainland is a wetland. Runoff is very slow and is a relatively small component of the water balance for several reasons. Hydraulic gradients are quite small due to low surface elevations above mean sea level and low surface gradients to streams, the rivers and the sounds. Rates of subsurface lateral flow are relatively low when the water table is below the zones of high hydraulic conductivity in the upper fibrous layer of the organic soils or the A horizon of the mineral soils. The saturated hydraulic conductivity (K_{sat}) of mucks is relatively low. In Belhaven and Pungo mucks in Tyrell County, Skaggs et al. (1980) measured average values of K_{sat} of 0.1 m/day and 0.08 m/day, respectively. In Dare and Pungo mucks in Carteret County, Amatya et al. (1997) measured average values of K_{sat} of 0.03 m/day and 0.1 m/day respectively. The loamy sediments below the organic soils also have quite low saturated hydraulic conductivity. In the Hofmann Forest, Daniels et al. (1978) measured average values of K_{sat} ranging from about 0.4 m/day for loamy sand to 0.0007 m/day for clay. From their studies of the morphology of the subsurface sediments throughout the eastern Coastal Plain, Daniels et al. (1978) concluded that gley colors represent zones of minimal or no water movement.

The hydrology of the Dare County mainland is influenced mainly by the interaction of rainfall and evapotranspiration (ET). As noted above, rainfall, on the average, is relatively well distributed throughout the year. Water tables are near the surface in the mineral soils and at or above the surface in the organic soils during the winter period of low ET. Water tables then decline through the growing season in response to ET to lows in September when PET begins to decline. The rate of fall soil water recharge and water table rise then is dependent on the pattern of late summer/early fall rainfall. Maritime low pressure systems, including an occasional hurricane can produce large rainfall events that result in rapid recharge.

The hydrography of the Dare County mainland is dominated by its position as a peninsula. All drainage flows through relatively short distances to the Alligator River, or the Albemarle, Croatan, or Pamlico Sounds. Only two major streams, Milltail Creek and Whipping Creek drain the interior of the peninsula and the channels of the former tributaries of these creeks are filled with peat. Flow in the streams is very slow due to the low relief and flow stagnation or reversal in the downstream portions is common due to tidal influence. Regular lunar tidal fluctuation on the Pamlico Sound margin averages about 0.3 m. Irregular wind tides from the Alligator River or the sounds can be much higher and flooding of the lower elevation areas of the peninsula occurs infrequently. Natural lakes on the peninsula consist of two types. Several lakes are

Table 2. Climatic normals at Manteo Airport for the period 1966-1990.

□WETS Station : MANTEO AIRPORT, NC5303 CREATION DATE: 6/24/96
Latitude: 3555 Longitude: 07542 Elevation: 10
State FIPS/County(FIPS): 37055 County Name: Dare
Start yr. - 1966 End yr. - 1990

	Temperature (Degrees F.)			Precipitation (Inches)				
					30% chance will have		avg # of days w/.1 or more	avg total snow fall
Month	avg daily max	avg daily min	avg	avg	less than	more than		
January	52.4	34.7	43.5	4.37	3.33	5.09	8	0.1
February	54.1	35.3	44.7	3.73	2.65	4.41	5	0.6
March	61.7	42.5	52.1	4.42	3.06	5.26	7	0.0
April	69.9	49.8	59.9	3.45	2.07	4.18	5	0.0
May	76.6	59.1	67.8	4.67	2.78	5.67	7	0.0
June	83.5	66.7	75.1	4.30	3.01	5.11	6	0.0
July	87.3	71.2	79.2	5.33	3.65	6.35	7	0.0
August	86.9	71.2	79.0	5.79	3.77	6.95	7	0.0
September	81.7	66.4	74.0	4.67	2.41	5.71	5	0.0
October	72.8	56.6	64.7	3.97	2.12	4.85	5	0.0
November	64.4	47.4	55.9	3.92	2.62	4.70	5	0.0
December	56.9	39.4	48.1	3.76	2.40	4.53	6	0.5
Annual	-----	-----	-----	------	44.86	52.61	--	----
Average	70.7	53.4	62.0	------	------	------	--	----
Total	-----	-----	-----	52.38	------	------	73	1.2

GROWING SEASON DATES

	Temperature		
Probability	24 F or higher	28 F or higher	32 F or higher
	Beginning and Ending Dates Growing Season Length		
50 percent *	2/17 to 12/29 316 days	3/ 8 to 12/ 9 276 days	3/29 to 11/28 244 days
70 percent *	2/10 to ----- 330 days	3/ 3 to 12/14 287 days	3/24 to 12/ 4 254 days

* Percent chance of the growing season occurring between the Beginning and Ending dates.

located along the channels of Milltail and Whipping Creeks. The geologic history of these lakes is likely related to blocked drainage in the streams when sea level was lower. As sea level rose, the water depth in the lakes was too deep for emergent vegetation to proliferate and form peat. A typical pocosin lake is located in the large pocosin on the southeast corner of the peninsula. As with such lakes in other pocosins, the geologic origin is speculative. Back Lake may be the deepest portion of a Carolina bay that has become submerged in peat or it may have been formed by ground fire.

The natural hydrography of the Dare County peninsula has been significantly altered by access roads and drainage systems. In the north-central portion of the peninsula, drainage for agriculture that was established several decades ago is still in operation in the Alligator River National Wildlife Refuge. Farther south, lateral drainage ditches were installed in several forested areas by Westvaco several decades ago with the intent of harvesting the natural stands and establishing loblolly pine (*Pinus taeda*) plantations. Those ditches now provide little drainage effect. In the southern portion of the peninsula, ditches are present only along access roads that were originally built to facilitate timber harvesting. Many such ditches were connected to outlets to assist in draining the road fills. The roads also have caused alterations in the natural hydrography, particularly the north-south roads that parallel the Alligator River. The roads block surface runoff through low lying areas during high water table conditions and also likely block the much slower rates of subsurface flow.

The hydrologic influence of the deep roadside ditches is debatable. At the higher elevations where the greatest hydraulic gradients occur, the ditches likely contribute to increased rates of runoff compared to natural conditions when water tables are high. When the water table declines below the surface zones of high K_{sat}, subsurface flow to the roadside ditches is very slow and the drainage effect is negligible. At the lower elevations, hydraulic gradients are very low and the ditches simply represent zones of tidal influx and efflux similar to natural creeks. Another factor in the hydrologic impact of the higher elevation roadside ditches is that many likely intersect the zone of shelly sands below the surface layer of loamy to clayey sediments. Such situations would provide a connection to a layer of much higher K_{sat} for near surface ground water that had not previously existed. Because of the low hydraulic gradients, this situation is probably not significant in contributing to hydrologic alteration.

SITE DESCRIPTION – STUDY AREA

General Description

The two blocks selected for intensive hydrologic study are located adjacent to the northern perimeter of the Air Force impact zone (Figures 1 and 2). The blocks are referred to as Ash block and Waterfield block throughout the report. Ash block is bounded by Faircloth Road on the east, Waterfield Road on the north, Beechland Road on the west and Ash Road on the south and contains 128.7 ha. Waterfield block is bounded by Faircloth Road on the east, Jackson Road on the north, Beechland Road on the west and Waterfield Road on the south and contains 104.4 ha. Each block is bounded by roadside ditches on the east, south and west that are interconnected. The roadside ditches on the north side of Ash and Waterfield Roads (no ditch on south sides) both connect at both ends to the much larger and deeper ditches along Faircloth Road (west side, no ditch on east side) and Beechland Road (east side, no ditch on west side).

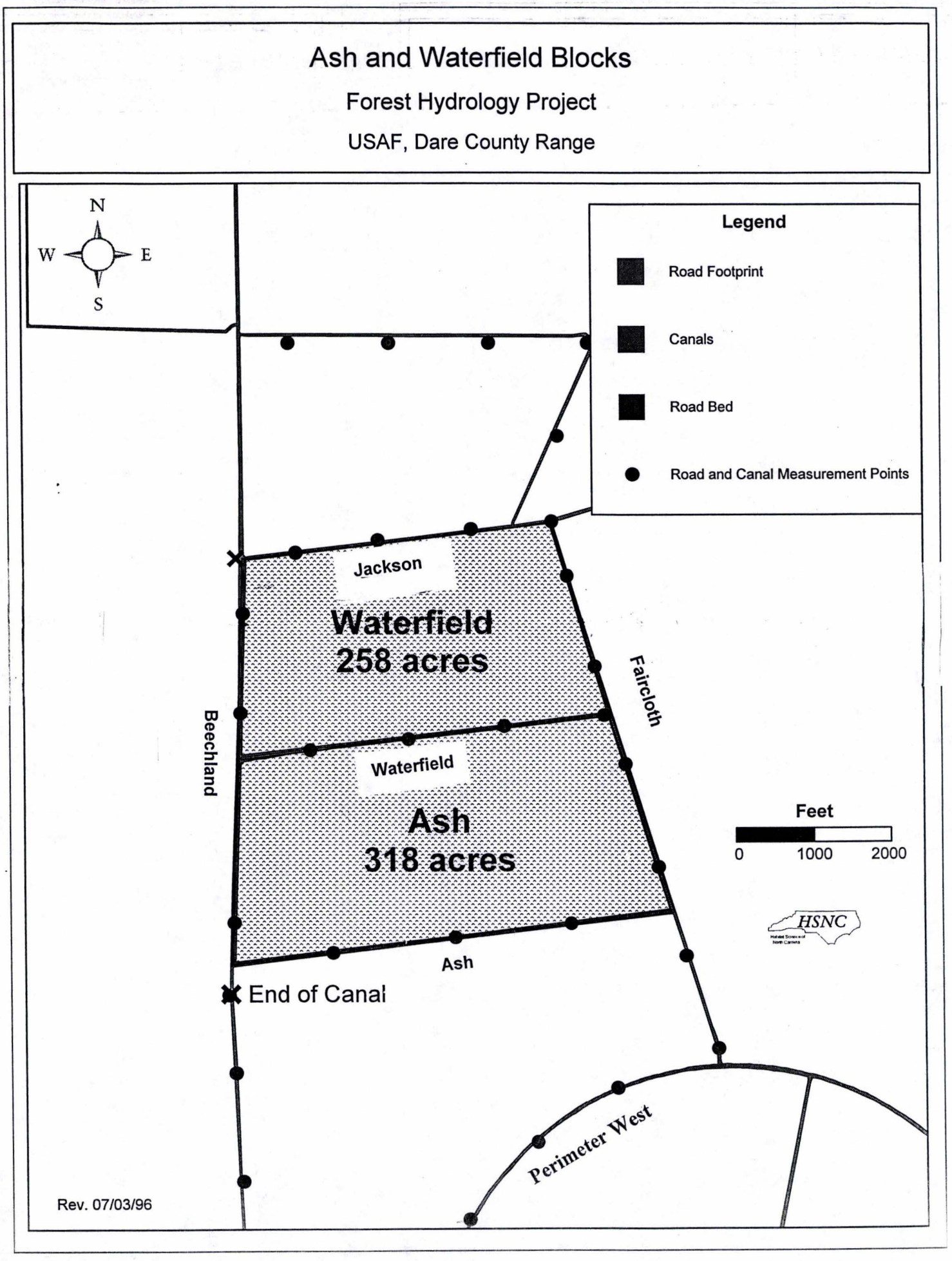
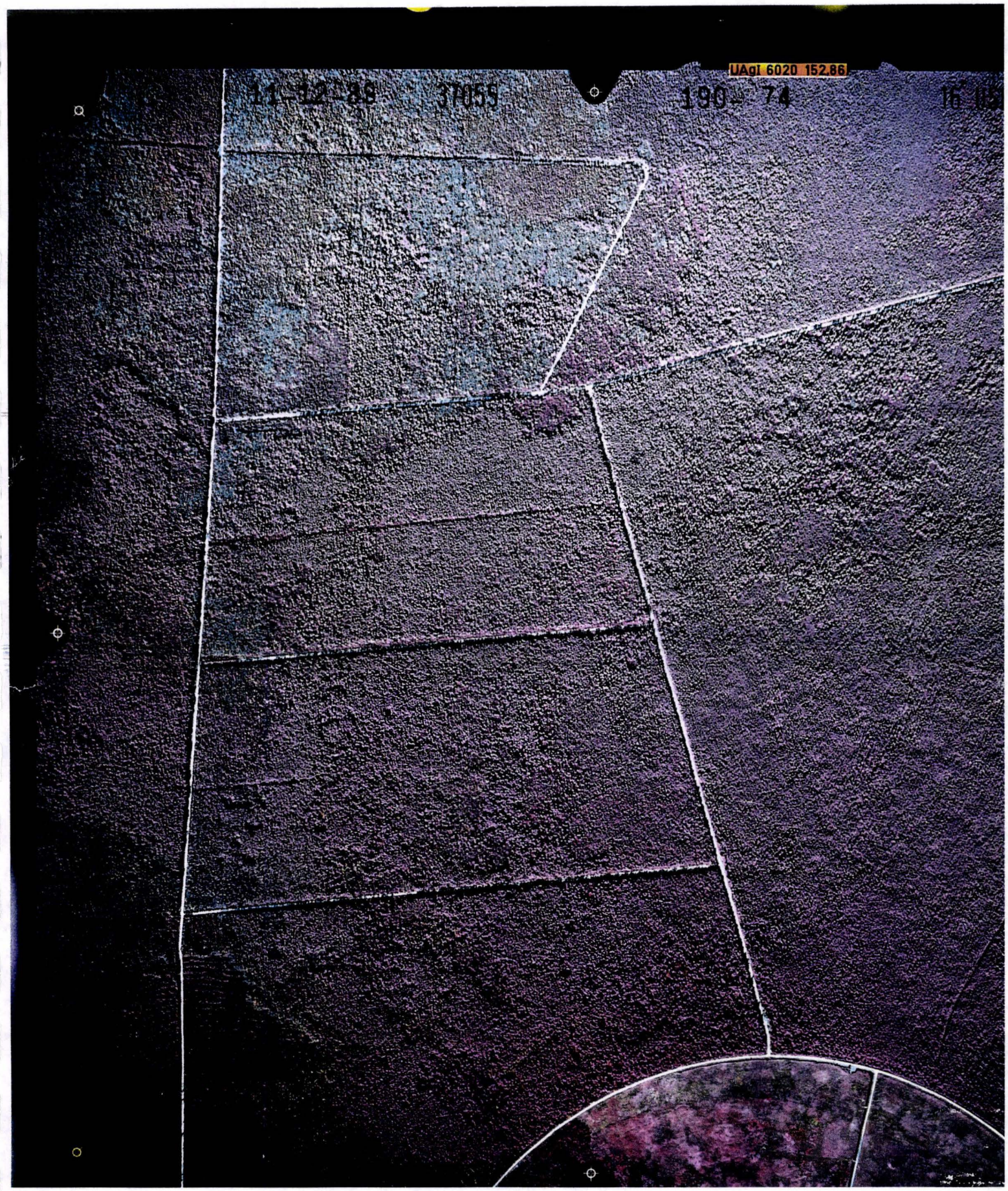


Figure 1. Map of the vicinity of the study blocks.

Figure 2. Infra-red color aerial photo of the vicinity of the study blocks.



The Faircloth Road ditch terminates at the south side of Jackson Road and does not connect to the Jackson Road ditch (north side, no ditch on south side). The Faircloth ditch connects at its south end to the ditch beside Perimeter Road West. The Beechland Road ditch continues north of Waterfield block and connects to the Jackson Road ditch but terminates just south of the Ash block. The pattern of flow in the ditches is described below under **WATER MANAGEMENT AND IMPACT ON RUNOFF**.

Topography

To determine water table elevations and soil surface elevations, leveling was conducted from Bench Mark "Land" (corner of Jackson and Faircloth Roads) to the first couple of wells closest to the road at the end of each transect. The unsteady nature of the organic soil surface made data obtained from instrument set-ups off the road suspect. However, the surface elevations that Norton Webster felt were reasonably accurate are noted on Figure 4 at the well locations. As noted in the **INTRODUCTION**, relief is present at three scales. At the regional scale, there is a very small surface gradient in the longitudinal direction across both blocks of decreasing elevation from east to west. That gradient is about 0.3 m in the 1380 m length of Waterfield block and about 0.3 m in the 1640 m length of Ash block or about 0.02 % for both blocks. There does not appear to be a general surface gradient in the south to north direction across either the 810 m width of Waterfield block or the 780 m width of Ash block except for the western end of the blocks. There is a decrease in elevation of about 0.1 m between the Ash west wells and the Waterfield west wells. That difference seems to be greater on the western side of Beechland Road. There also appears to be a slight downward gradient to the northwest in the northwest corner of Waterfield block. At the local scale, there is random undulation on a scale of tens of metres across the blocks that contributes to relief of about 0.3 m. Microrelief of 0.3 – 1.0+ m is common due to hummocks of fibrous peat formed at the bases of large pine trees or large shrubs.

Soils

The soils in Ash block are mapped predominantly as Roper muck with a small strip of Ponzer muck on the east end and a small area of Belhaven and Pungo mucks on the northwest corner (Figure 3). In the Waterfield block, the soils are mapped predominantly as Ponzer muck with a small area of Belhaven and Pungo mucks in the southwest corner (Tant, 1992). The classifications of the series and the nominal organic layer depths are listed in Table 1. The depths of the organic surface measured at the well locations show that the organic layer is generally thicker than the described series of each mapping unit (Table 3). The organic layer depth listed for each well in Table 3 was generally noted when augering the bore hole for the well. The depth of the organic surface at several wells (AE2, AE4, FW2, WE1, and WE2) was later rechecked with a length of rebar used to probe to the mineral soil. There is a very gradual transition at the bottom of the organic layer from muck texture, to mucky mineral, to the mineral soil. Thus, judging the level at which muck changes to mucky mineral involves some error, either when checking by auger or with a probe. In the Ash block, most of the area mapped as Roper muck better fits the Ponzer muck description with a relatively small area of Roper muck at the western end that apparently overlies a "ridge" in the underlying sediment that extends from the Ash block across Beechland Road. The soil throughout the Waterfield block better fits the Belhaven muck description.

Figure 3. Soils map of the vicinity of the study blocks.

Note that variation in the elevation of the soil surface somewhat "masks" the variation in the elevation of the mineral soil surface. For example, there is a decrease in surface elevation of about 0.3 m from east to west across Ash block. There is a corresponding decrease in the thickness of the organic layer of about 0.5 m. In areas where there appears to be little variation in the nominal surface elevation (measured in the bottoms of the depressions), there is significant random variation in the thickness of the organic surface.

The mineral layer underneath the organic surface at most of the well locations is finer textured than described in the typical Ponzer and Belhaven profiles (Tant, 1992). With massive structure, that mineral layer is gleyed and relatively plastic with texture ranging from sandy clay loam to clay loam. That layer was generally about 0.3 –0.5 m in thickness and was underlain by sand that was encountered in several borings to 2 m or more. The clayey layer was not encountered immediately below the organic surface at all well locations, so it is either discontinuous or has an undulating surface. Such gleyed clayey layers below organic surfaces usually have very low K_{sat} as noted by Daniels, et al. (1978) and serve as a restrictive layer if relatively thick and continuous. Thus, we can expect that the water table will likely fluctuate from the surface to the top of the restrictive layer for most of the year, except during extremely dry periods. To determine whether the clay layer was significantly limiting downward percolation, seven piezometers that were screened below the clay layer were installed in mid-summer, 1997.

Table 3. Depth to mineral sediment under the organic surface at each well.

Well No., Ash	**Depth to Mineral, cm**	**Well No., Waterfield**	**Depth to Mineral, cm**
AE1	88	FW2	113
AE2	81	FW1	129
AE3	100	WE1	152
AE4	98	WE2	108
AC	85	WE3	116
AW4	56	WE4	98
AW3	40	WC	80
AW2	45	WW4	no clay
AW1	40	WW3	no clay
BA1	54	WW2	83
BA2	46	WW1	84
AS1	84	BW1	88
AS2	83	BW2	84
AS3	75	WS1	80
AN3	89	WS2	80
AN2	90	WS3	94
AN1	109	WN3	130
		WN2	125
		WN1	115
		JW1	90
		JW2	55

Note: The notation of well numbers is explained in **WATER TABLE** below.

Vegetation

The forest stand on the Ash and Waterfield blocks consists of a pond pine overstory with a midstory dominated by bays that is classified by Schafale and Weakley (1990) as pond pine woodland (Figure 2). The lower elevation areas with shallower water tables on the northern and western sides of Waterfield block and the northwest and southwest corners of Ash block have a more mixed overstory with pine and hardwoods

Pond pine woodland:

Overstory – *Pinus serotina*

Midstory – *Persea palustris, Acer rubrum*

Understory – *Ilex glabra, Lyonia lucida*

In the mixed pine hardwood area, *Nyssa biflora and Acer rubrum* are also present in the overstory.

WEATHER

The weather station was installed (beginning on March 24, 1997) in an area located about 100 m south of the Dare County Air Force Range (DCR) headquarters in a large open area that is an aircraft approach zone for the impact area. The pocosin shrub vegetation is maintained in that area but trees are excluded. The shrub vegetation was lopped to 2 m height in a circular area of about 50 m radius around the climate station mounting tower and will be maintained at about that height . In that setting, the wind and radiation sensors are mounted at 2 m height above the canopy which is the appropriate height for use of the data in many different ET equations. To provide stability for the sensor mounts in the organic soil of the area in which the station is mounted, a triangle of galvanized steel pipe, 32 mm (1.25 in) ID was driven to depths of 3 m and stabilized with pipe cross-members.

The weather station consists of a Campbell Scientific, Inc. CR10X datalogger supplied with the following sensors: anemometer, wind direction probe, temperature and relative humidity probe, pyranometer, net radiometer, soil temperature probe and tipping bucket rain gauge. The datalogger was set to interrogate the sensors at one-minute intervals and half-hourly totals or means of climatic variables were recorded as appropriate. Half-hourly totals/means of relative humidity, air temperature, wind speed and direction, solar radiation, and net radiation were collected. Rainfall totals were recorded at five-minute intervals to provide data on short-term intensities when needed. The data collection protocols were standardized with those long established for data collection at the network of climatic stations at NCSU agricultural experiment stations around the state. Software written by Dr. Devendra Amatya, Research Associate in the NCSU Department of Biological and Agricultural Engineering, was used to compute estimates of total daily PET using the Penman-Monteith method. The objective in estimating daily PET is, of course, to develop methods for predicting days or possibly weeks in advance when the soil moisture and fuel moisture conditions will be optimal for conducting a prescribed burn.

A second tipping bucket rain gauge was installed was installed in July, 1997 in a large opening in Waterfield block that had been created by a pine beetle infestation. The purpose of that gauge was to provide more accurate measurement of rainfall since the weather station was located about 5 km from the study site.

WATER TABLE

The network of water table wells was established as transects at 90 degree angles across the study blocks (Figure 4). The network was designed to address several objectives:

- transects within the study blocks – determine temporal variation of the water table at different locations and depths; determine spatial variation in both directions across the study blocks; provide data to estimate hydraulic heads across the blocks; provide intensive sampling of the water table variation to assist in making recommendations about minimum cost-effective sampling.
- transects extended across the roads at three locations – determine if there were significant hydraulic heads across the roads; compare water table profiles away from the road with and without a road side ditch.
- wells and piezometers installed to extend below the clay layer – determine if the clay layer significantly limited downward percolation.

The wells within the segments of the transects were spaced at standard distances from the road centerlines in accordance with the following scheme:

1. East-west segments
   A. well 1 – 50' from road; e.g., well no. 1 on the easterly segment of the Ash east-west transect is denoted as AE1
   B. well 2 – 250' from road
   C. well 3 – 500' from road
   D. well 4 – 1000' from road
   E. well C – placed at center of the block; e.g., the center well on Ash block is denoted as AC
2. North-south segments
   A. well 1 – 50' from road; e.g., well no. 1 on the northerly segment of the Waterfield north-south transect is denoted as WN1
   B. well 2 – 250' from road
   C. well 3 – 500' from road
3. Additional wells
   A. Pairs of wells installed on opposite sides of Faircloth, Jackson, and Beechland Roads from the study blocks
      (1) well 1 – 50' from road; e.g., well no. 1 on the western side of Beechland Road from the Ash block is denoted as BA1
      (2) well 2 – 250' from road
   B. Extra well installed adjacent to and deeper than an original well – denoted with the same number as the original well with an "a" suffix
   C. Piezometer installed adjacent to an original well – denoted with the same number as the original well with a "p" suffix

The depths to which the wells and piezometers were installed and the relative surface elevations at the wells are shown in Table 4 below.

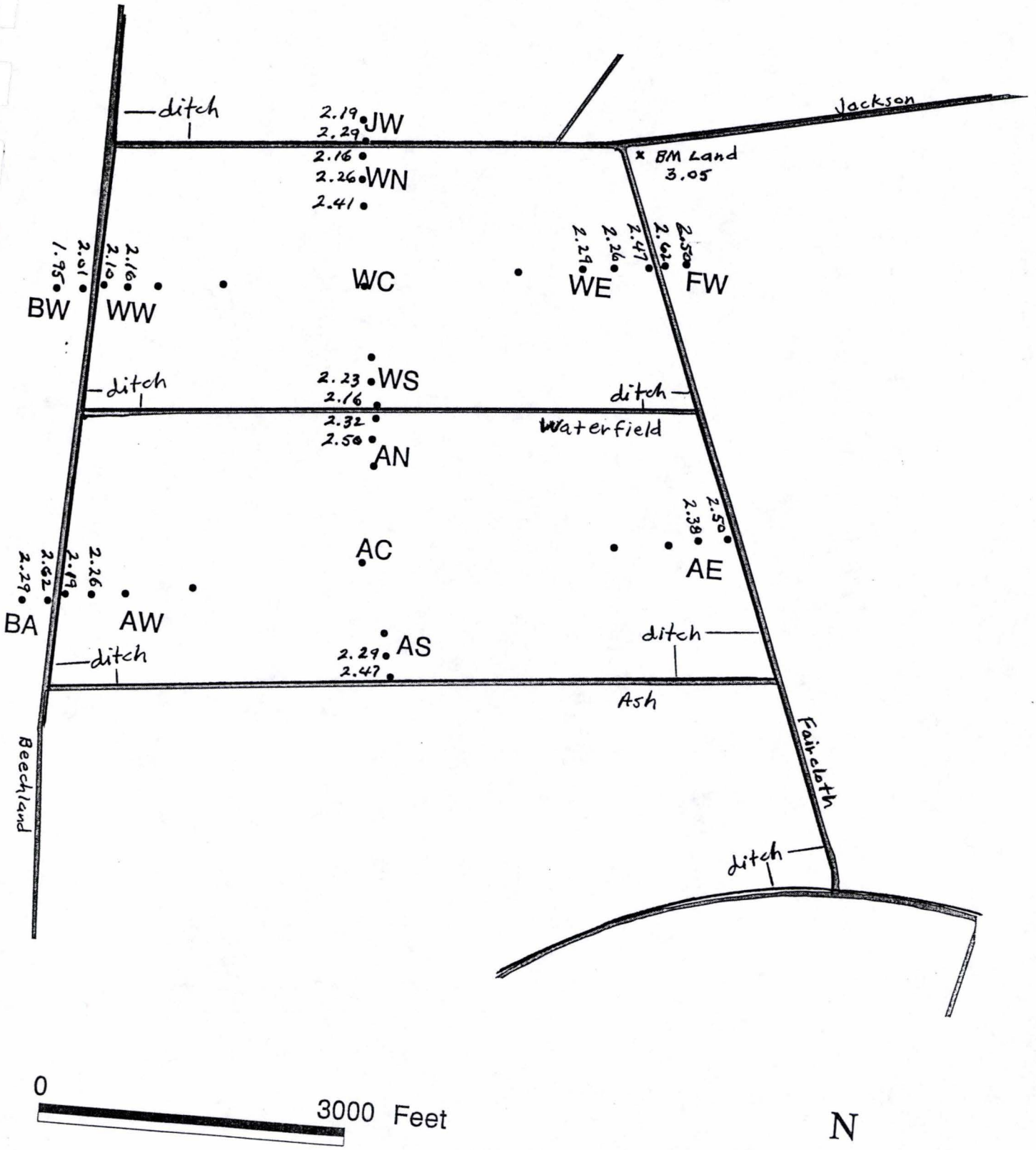


Figure 4. Water table well locations in the study area. Surface elevations at wells are in metres relative to e elevation of BM Land set at 10.00 ft (3.05 m).

Table 4. Well depths and relative surface elevations at the wells.

Well No., Ash	Well Depth, cm	Elevation, cm	Well No., Waterfield	Well Depth, cm	Elevation, cm
AE1	96	250	FW2	130	250
AE1p	270	241	FW1	150	262
AE2	103	238	WE1	140	247
AE3	120		WE1p	270	204
AE4	101		WE2	100	226
AC	116		WE2p	270	210
AW4	81		WE3	110	229
AW3	79		WE4	95	
AW2	64	226	WC	76	
AW1	50	219	WW4	90	
BA1	91	262	WW3	90	
BA1a	140		WW2	90	216
BA2	80	229	WW1	90	210
AS1	86	247	BW1	90	201
AS1a	120	232	BW2	96	195
AS2	97	229	WS1	72	216
AS2p	270	241	WS1a	90	
AS3	94		WS1p	270	
AS3a	270		WS2	90	223
AN3	113		WS3	97	
AN2	103	250	WN3	135	
AN2p	270		WN2	130	226
AN1	121	232	WN1	125	216
AN1p	270		JW1	100	229
			JW2	80	219

To follow the water table hydroperiod and also determine the hydraulic head below the fine textured layer, we have used two types of well designs. The standard water table well consisted of 10 cm ID schedule 40 PVC screen (0.010 diameter slots) and casing sections. Each well was installed with the closed bottom of the well extending into the mineral layer about 25-30 cm and the screen extending to within about 20 cm of the surface. An envelope of No. 2 well sand was installed in the annular space around each well screen and the annular space around the casing at the surface was sealed with clay. Water level recorders can be installed on any of the 15 such wells in each study block. A smaller diameter piezometer (5 cm ID), designed for making only manual measurements, was installed close to several of the standard wells with the screen open only below the fine-textured mineral layer.

Sixteen wells were fitted with water level recorders with the dataloggers set to record the water table at 15 min intervals. The recorders consist of a float sensor with a 10-turn potentiometer coupled to a Campbell Scientific, Inc. CR 500 datalogger. The float sensors were designed and built by project staff to provide sensitivity and accuracy ≤ 3.0 mm. Each sensor was tested and

calibrated with a datalogger in the laboratory and the sensitivity was usually about 2.0 mm. Each recorder was mounted inside a heavy gauge plastic weather-proof box that was secured on top of the well with a rubber sleeve. The water level in all other wells and piezometers has been measured manually at approximate weekly intervals. The water level recorders originally were placed on wells in each of the two blocks to provide continuous hydrographs on a subset of the wells within the main east-west and north-south transects. To maximize our information on the water table behavior through the dry period of the summer, the recorders were moved from wells that went dry to those that still had water in them.

TIDAL HYDROPERIOD

To determine the potential impact of tidal fluctuations of the water level in creeks and ditches, two tide gauges were installed at two of the major ditch outlets of the DCR, Long Shoal River and the Lake Worth Road ditch at Stumpy Point in July and August. Each gauge consisted of a double stilling well with the water level recorder mounted inside the outer well for security. The outer well consisted of corrugated steel pipe, 46 cm (18 in) ID, that was driven into the bottom sediments and secured to the bridge structure at each location with steel straps. A line of small holes allowed water level equalization. A 10 cm (4 in) ID PVC well screen with necessary casing of schedule 40 PVC was mounted and secured inside the outer well. The water level recorder was mounted over the PVC well and the top of the steel well was secured with a locking cover.

SOIL MOISTURE

Samples for determining the moisture content as percent by weight of the three major layers of the organic soil system were collected on January 4, 1998. The sampling scheme was designed to provide information on the effects of four different factors on soil moisture content:

- Location within the study blocks. The samples were collected adjacent to eight wells within each study block - wells 1 and 2 at each of the four quadrant locations of the transect segments.
- Microsite elevation differences. At each sampling point, samples were collected at three different points along the typical microsite elevational gradient - low area (subsample a), halfway up the side of the nearest adjacent hummock formed around a pond pine tree (subsample b), and the top of that same hummock (subsample c).
- Depth. Three different depths were sampled at a – surface litter (no letter following location letter), the fibric layer below the litter (f suffix following location letter), and the muck just below the fibric layer (m subsample designation). Two different depths were sampled at a and b, the surface litter layer and the fibric layer. Table 5. shows an example of the soil sample designations.
- Water table depth. The water table level was measured in the well adjacent to each sample point at the time of sampling.

Table 5. Example of the sample numbering scheme for well 1 on the north quadrant of Ash block.

Sample Number	Location of Sample
AN1 a	Low area, surface litter
AN1 af	Low area, fibric layer
AN1 m	Low area, muck layer
AN1 b	Halfway up hummock, surface litter
AN1 bf	Halfway up hummock, fibric layer
AN1 c	Top of hummock, surface litter
AN1 cf	Top of hummock, fibric layer

Samples of about 60-70 cm^3 volume were sealed in plastic bags. At the lab, the plastic bags were split open and placed inside paper bags for weighing and drying. The samples were dried to constant weight at 70° C in a forced draft oven and moisture content by weight was determined.

RESULTS AND DISCUSSION

CLIMATE

The measured daily climate data collected at the DCR weather station is shown in Appendix 1 and the computed daily PET totals are shown in Appendix 2. The maritime climate is quite apparent in the data of Appendix 1, in particular, the wind behavior and the relative humidity. The wind is never calm and the average speed exceeded 4 m/s (14 mph) on many days. Note also a very important factor to a fire manager at DCR is the prevailing southerly to southwesterly wind direction. On only 15 days of the 264 days did the average daily wind direction fall in the northeast quadrant. Those episodes were brief, often only one day, and therefore are likely unpredictable. The position of DCR on the Dare County peninsula means that the shift from land to sea breeze on hot summer nights probably does not constitute the wind direction reversal common in many coastal zones. It is likely that the sea breeze is often a southerly to southeasterly flow. The average daily relative humidity was quite high throughout the period of record from April to December. There was one two-day period in mid-April with average daily relative humidity below 50% (and also high winds), but for the reminder of the year, the values seldom fell below 70%.

As noted in the **METHODS** section, two rain gauges were installed at the DCR, one at the weather station located near the office and one in an opening in the forest stand on Waterfield block. We intended to use the data from the Waterfield gauge for comparison with water table changes since an onsite gauge would provide more accurate rainfall data than the one at the weather station 5 km away. However, a comparison of the data for the two rain gauges that was done recently led to concern about the accuracy of the Waterfield gauge. There were random differences in the catch of the two gauges during the first couple of months of record, but the Waterfield gauge recorded rainfall amounts 2-3 times that of the weather station gauge during October to December. A comparison of event rainfall amounts from those two gauges with data from the National Weather Service volunteer observer stations at New Holland (about 40 km SW of DCR) and Manteo Airport (about 30 km NE of DCR) confirmed the conclusion that the

Waterfield gauge was not operating properly. Therefore, all rainfall data used in the analyses conducted for this report is that measured at the DCR weather station.

Noted in Table 6 below is the weekly pattern of rainfall and PET for the period of the study. Rainfall totals for June and August at DCR were less than 50% of normal (compared to Manteo Airport data) and were significantly below normal for all other months, except for September and November. The total rainfall amount for the period of record (May 7 – December 31) was 80% of normal. Comparison of the rainfall amounts measured at DCR to those measured at Manteo and New Holland shows the random differences common over such distances.

The PET data show that the weekly total PET at DCR consistently exceeded the weekly rainfall total from May – August and then during September – December, a number of weeks had excess rainfall. It is interesting to note that the first three weeks of December had little rain and relatively high PET for that time of year.

That 1997 was a year of above normal PET is evidenced by data on rainfall and PET for the years 1993-1997 for the Tidewater Research Station (data provided by Dr. Devendra Amatya, NCSU Department of Biological and Agricultural Engineering). That station is located a few kilometres east of Plymouth in Washington County, NC, about 75 km northwest of DCR. Rainfall at the Tidewater Station in 1997 was much lower than the previous four years except for 1993. Conversely, PET at the Tidewater Station in 1997 was significantly higher than any of the previous four years.

Table 6. 1997 weekly totals of rainfall and PET (mm) at the DCR weather station and rainfall at the Manteo Airport and New Holland observer stations; 1966-1990 mean annual (normal) rainfall at the Manteo Airport.

Julian Day	DCR Weather Station		New Holland Rainfall	Manteo AP Rainfall	Manteo AP Normal
	Rainfall	PET			
May					
127	9	45	8	0	
134	43	41	36	17	
141	2	64	4	18	
151	38	51	9	19	
May Total	90	201	57	54	119
June					
158	10	16	14	8	
165	26	31	5	42	
172	0	35	27	0	
181	15	50	19	19	
June Total	51	132	65	69	109
July					
188	35	28	50	17	
195	5	21	10	25	
202	5	37	0	6	

Julian Day	DCR Weather Station		New Holland Rainfall	Manteo AP Rainfall	Manteo AP Normal
	Rainfall	PET			
212	28	25	70	10	
July Total	101	121	130	58	135
August					
219	25	37	13	42	
226	0	40	0	0	
233	25	39	9	41	
243	6	42	5	0	
Aug. Total	56	158	27	83	147
September					
250	12	35	0	0	
257	43	21	58	25	
264	7	23	31	2	
273	87	26	149	89	
Sept. Total	149	105	238	116	119
October					
280	1	22	0	0	
287	1	21	0	0	
294	40	8	26	29	
304	28	18	32	25	
Oct. Total	70	69	58	54	101
November					
311	53†	15*	53	35	
318	33†	18*	33	30	
325	6	28	4	4	
334	39	37	44	24	
Nov. Total	131	98	134	93	100
December					
341	3	24	#	0	
348	13	48	#	19	
355	1	45	#	0	
365	74	42	#	99	
Dec. Total	91	159	#	118	96
Period Total	739	1043	709	645	926

Data not available

* Estimated

† DCR data not available, substituted New Holland data

Table 7. Rainfall and PET at the Tidewater Research Station, Plymouth, NC.

Year	Rainfall, mm	PET, mm
1993	1004	960
1994	1357	917

Year	Rainfall, mm	PET, mm
1995	1359	945
1996	1576	911
1997	1046	1013

WATER MANAGEMENT AND IMPACT ON RUNOFF

Water management was already in place in the vicinity of the study blocks when this study was initiated. Development of that water management system was accomplished by taking advantage of roads for use as dams and installation of control structures at strategic locations in ditches. The water management system installed by the N.C. Division of Forest Resources staff in the vicinity of the impact zones has several objectives:

- maintain the water table as close the surface as possible during aerial training operations to minimize ignition and spread potential on the impact zones and within adjacent forest stands.
- store water in the ditch system and provide for rapid movement of large quantities of water when needed for fire suppression.
- temporarily lower the water table in sections of the impact zones when needed to facilitate mowing operations or prescribed burning.

Data collected and field observations made during the course of this study indicate that significant runoff from the study blocks occurs only during very high water table conditions when water flows across Beechland Road from the western ends of the study blocks. During most of the year, the water management system limits subsurface lateral flow away from the study blocks to negligible quantities and the water table level is controlled mainly by the interaction of rainfall and ET. A GIS map of the DCR showing locations of culverts and control structures and the flow of water in the ditches under high water table conditions is included in Appendix 15.

The older segments of the road and ditch system on the range were originally installed to facilitate forest management by previous owners. The roads were constructed by digging one deep dragline ditch and using the spoil to build up the road bed adjacent to the ditch. The roadside ditches were connected to collector ditches that in turn discharged to streams or directly to the Alligator River or to the Pamlico Sound. Providing for discharge of water from the roadside ditches had two purposes. Providing some drainage from those ditches aided in draining the road bed during wet conditions. Westvaco foresters also installed lateral ditches in some blocks in what is now the northern section of the range with the intent of harvesting the natural stands and establishing loblolly pine plantations. Many of the roads that were built specifically for construction and management of the impact zones have ditches on both sides which facilitates water management.

Runoff from the Ash and Waterfield blocks is severely restricted due to the presence of the roads. The roads serve as dams that block lateral flow over the surface or through the fibric layer of the organic soil when the water table is at or above the surface. Under natural conditions, of course, subsurface lateral flow is very slow to nil when the water table is below the fibric layer. Some seepage would likely occur through any of the roads if a high hydraulic head existed across them. However, the combination of low relief and ditch control structures limits hydraulic gradients across the blocks and across the boundaries of the blocks.

Due to the natural topography, lateral flow under high water table conditions in both blocks flows westward. We do not have detailed surface elevation measurements but several pieces of evidence show that the northwestern area of Ash block and the western and northern area of Waterfield block are part of a lower lying area of terrain that was a natural ephemeral drain prior to construction of the roads. The vegetation type in both blocks is mainly dense pond woods in the eastern and central sections of the blocks. The pond pine component gives way to nonriverine swamp forest dominated by hardwoods with a much denser shrub layer at the western ends of the blocks. The soil mapping units also are indicative of topographic variation (Figure 3). Ponzer muck (PoA) and Roper muck (RpA), with organic layers that are usually less than 1 m thick, occur on intermediate elevations. Belhaven muck (BvA) and Pungo muck (PuA), with organic layers thicker than 1 m, occur on the lower elevations. The tongue of Pungo and Belhaven soils that extends into the western ends of the blocks is indicative of the lower lying area that served as an ephemeral drain under natural conditions. When the water table is above the surface in the western ends of the blocks, water flows westward over Beechland Road in the vicinity of that zone of Pungo soil.

Incomplete connections to outlets combined with control structures in the roadside ditches greatly limits the rate of outflow under high water table conditions and prevents it entirely at lower water table conditions. The main outlet ditch along Faircloth Road and Perimeter Road West was cleaned prior to initiation of this study to facilitate water management. However, the culverts that connect the Faircloth and Beechland Road ditches across Ash and Waterfield Roads are in poor condition and partially blocked by sediment and debris. Water does not flow northward in the Beechland Road ditch north of Jackson Road because the natural topographic divide between the Milltail Creek and Whipping Creek watersheds is north of the Waterfield block. Flow in the Jackson Road ditch under high water table conditions is westward to Beechland Road and then southward due to a control structure at the intersection of Jackson Road and Ralph Road. Southward flow in the Beechland Road ditch (east side) flows east through the Ash road ditch to the Faircloth road ditch because the Beechland ditch terminates just south of Ash block and is not connected to the ditch on the west side of Beechland that begins at about the same point. The remnants of a log culvert under Beechland Road allows some seepage through the road fill but it does not contribute to significant runoff.

Outflow southward in the Faircloth Road ditch is the principal ditch discharge from the ditches around the study blocks. That flow is limited by a series of control structures in ditches around and within the Air Force impact zone. A structure at the Faircloth and Perimeter Roads intersection limits flow to the east and then south along Perimeter Road East toward the Long Shoal River outlet. A structure at the intersection of Perimeter Road and Air Force Lead Road limits flow westward to the Whipping Creek outlet. The very high water tables in the study blocks in late winter/early spring and hydraulic heads of up to 0.5 m noted across some of the control structures at various times show that seepage through the roads is minimal.

ADDITIONAL WATER MANAGEMENT INFRASTRUCTURE

Objective 2 of this research called for the design and implementation of a ditch system, including water management structures, needed to manipulate water levels on the paired watersheds. The U.S. Air Force provided funds to clean the ditches around the study blocks and the outlet ditch along Faircloth and Perimeter Roads to facilitate water management. Cleaning the ditches of

accumulated sediment and debris was accomplished in the spring of 1996. A draft plan was written (September, 1996; Appendix 3) for additional water management infrastructure development. That plan included:

- installation of a network of benchmarks to facilitate engineering design of the water management infrastructure and to facilitate determination of accurate elevations in and around the study blocks
- construction of new ditches along the northern sides of Ash and Waterfield blocks
- extending the outlet ditch on the western side of Beechland Road northward to Jackson Road
- replacing damaged culverts and installing new culverts to facilitate managing water in the ditches around each block separately
- installing control structures at strategic locations for water management in the vicinity of the study blocks

Assistance was provided to U.S. Air Force staff in developing cost estimates of the different components of the proposed work. Billy Lumpkin, regional supervisor for the N.C. Geodetic Survey, provided invaluable assistance in planning a network of benchmarks. The U.S. Air Force purchased materials for rod benchmarks and contracted with the U.S. Geological Survey for installation. Assistance was provided to the U.S.G.S. crew for installation of benchmarks in June/July of 1997. The network included benchmarks

- in the vicinity of the Air Force impact zone and DCR office
- a loop from highway 264 at the DCR main entrance, through the DCR along Faircloth, Jackson and Long Curve Roads back to highway 264 at Stumpy Point
- a loop along Beechland to Navy Lead and thence to the intersection of Dry Ridge and Alligator roads.

The U.S.G.S. report describing the bench marks is included as Appendix 4. Surveying of these bench marks has not yet been accomplished. After conducting standard RFP procedures through the Seymour Johnson AFB contracting office for bids on accomplishing the ditch, culvert and control structure work, U.S. Air Force staff found that completing that work was cost prohibitive.

WATER TABLE HYDROPERIOD

The water table data were collected during the period from May 7 (JD 127) to December 21 (JD 355). To illustrate the temporal and spatial variation of the water table, five different types of water table charts were produced. Selected charts are included in the narrative to illustrate results and the complete set of all charts is included in the appendix. Chart types are:

- Hydrographs of water table depth (manual readings, entire period of record) of each well with hyetograph of daily rainfall amounts measured at the DCR weather station (Appendices 5 & 6). Hydrographs of wells located at the low pocosin and high pocosin sites are also included (Appendix 12). Note that, on the charts, a line is used to connect successive water level measurements but those straight line segments are not representative of the temporal variability that occurred between the successive measurements. Where the water table fell below the bottom of a well in July and August, the connecting line was not included to indicate that the data were not available. Note that drawing conclusions about the water table response to a particular event is not possible from these hydrographs; their value lies in revealing seasonal trends of water table variation.
- Hydrographs of water table depth (daily datalogger readings, entire period of record) of wells on which the dataloggers were installed with hyetograph of daily rainfall measured at

the DCR weather station (Appendix 7). Because the dataloggers were moved among several wells when the water table fell below the bottoms of the wells, each hydrograph line is a combination of manual and datalogger measurements. These hydrographs illustrate, on a broad time scale, the temporal variation of water table depth due to rainfall and PET.

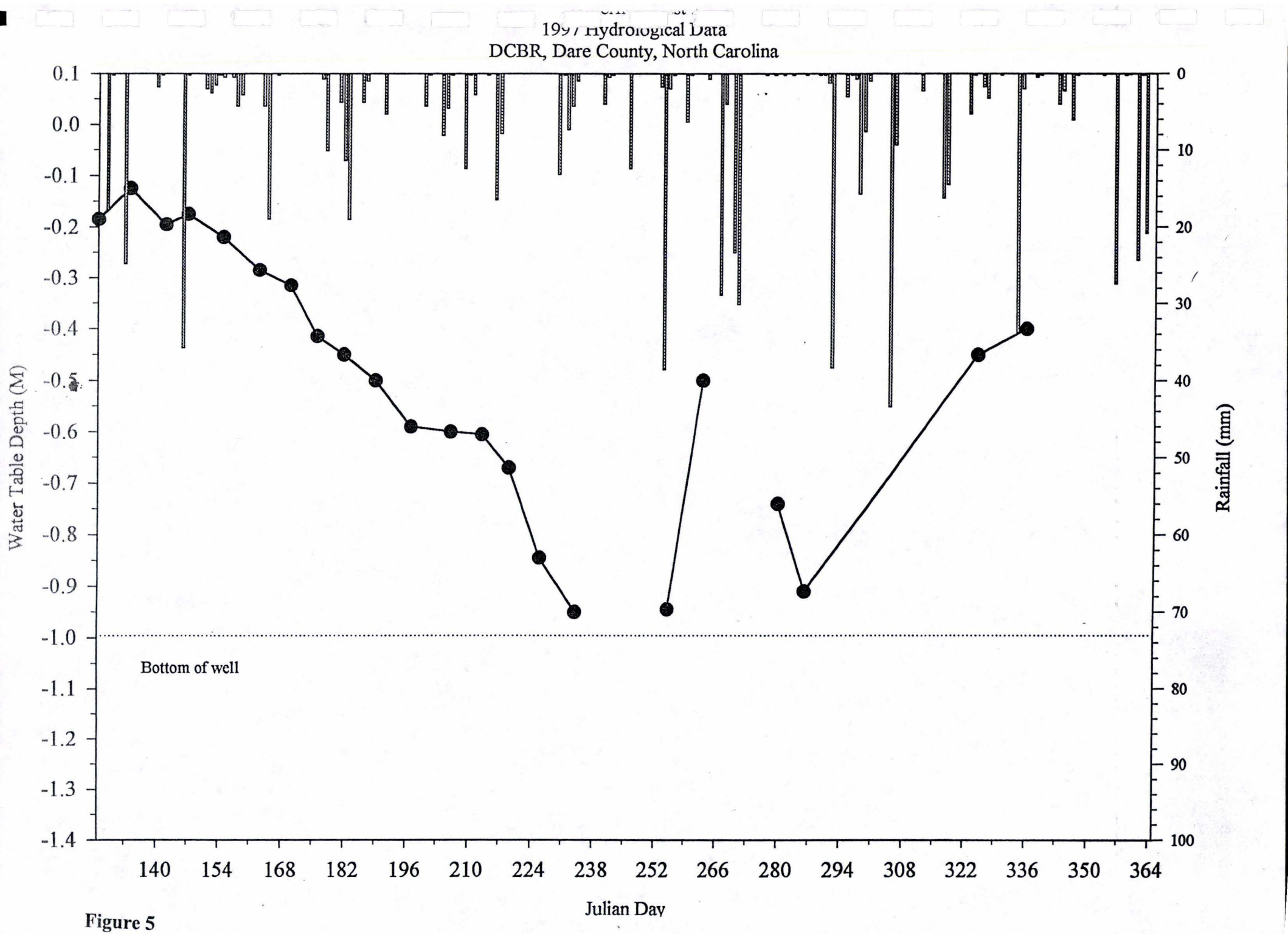
- Short-term hydrographs of water table depth (15-minute datalogger readings) with hyetographs of daily rainfall amounts and PET (Appendix 8). These hydrographs illustrate the short term variation of water table depth and the effects of rainfall and PET.
- Transects of water table depth among wells on the north-south and east-west transects across the study blocks for each date of manual water table measurement (Appendices 9-11). These charts illustrate the spatial variation of water table depth across the blocks and provide insight into the factors that influence that variation.
- Transects of water table elevation among wells on the north-south and east-west transects across the study blocks for which soil surface elevation is available for each date of manual water table measurement (Appendix 16). These charts have limited numbers of wells due to the limited elevation data but serve to indicate trends of water table elevation variation.

Temporal Variation of Water Table Depth

Seasonal Trend

The general trend of seasonal variation of the water table depth was a continuous decline from early May to a minimum in late summer (Appendices 5-7). The main network of water table wells was installed with the bottoms of the wells slightly into the clayey layer below the organic horizon because it was assumed that the water table likely would not decline lower than that level, about 1 m on the average. It became clear in late July that the water table was going to decline below the bottoms of most of the wells and into or below the clayey layer below the organic horizon. Therefore, several additional wells (numbered the same as the adjacent well with the suffix "A") and several piezometers (numbered the same as the adjacent well with the suffix "P") were installed adjacent to current wells at deeper depths at easily accessible locations (Table 4). Piezometers consisted of lengths of screen about 0.3 m long that were glued to a casing section and installed with the bottom of the screen at 2.7 m depth.

The water table depth increased at a average rate of about 0.75 cm/day during the period from early May to early August. The negative slope of the hydrograph was very similar, with a couple of important exceptions, for all wells within the two blocks, regardless of variability in water table depth at the beginning of the period. For example, compare the hydrographs along the east-west transect across Waterfield block from Faircloth Waterfield 2 to Beechland Waterfield 2 (Appendix 6). Comparing series of adjacent wells across that transect or comparing wells separated by great distance shows very similar patterns of rate of water table decline. An interesting comparison is WE2 versus WW4 (Figures 5 & 6). The water table depth averaged about 15-20 cm greater at WE2 than at WW2 during the early summer decline and the fall recharge. However, the rates of change of water table depth at the two locations were quite similar. Note that the frequent small rainfall events from about JD 200 to JD 215 had much less effect on the water table level at WE2 compared to WW4. Where the water table was at a depth of about 40 cm (WW4), some recharge occurred and resulted in a brief rise of the water table. Where the water table was at a depth of about 60 cm (WE2), the rainfall supplied ET losses but did not percolate down to the water table.


1997 Hydrological Data
DCBR, Dare County, North Carolina
Water Table Depth (M)
Rainfall (mm)
Julian Day
Bottom of well
0.1
0.0
-0.1
-0.2
-0.3
-0.4
-0.5
-0.6
-0.7
-0.8
-0.9
-1.0
-1.1
-1.2
-1.3
-1.4
0
10
20
30
40
50
60
70
80
90
100
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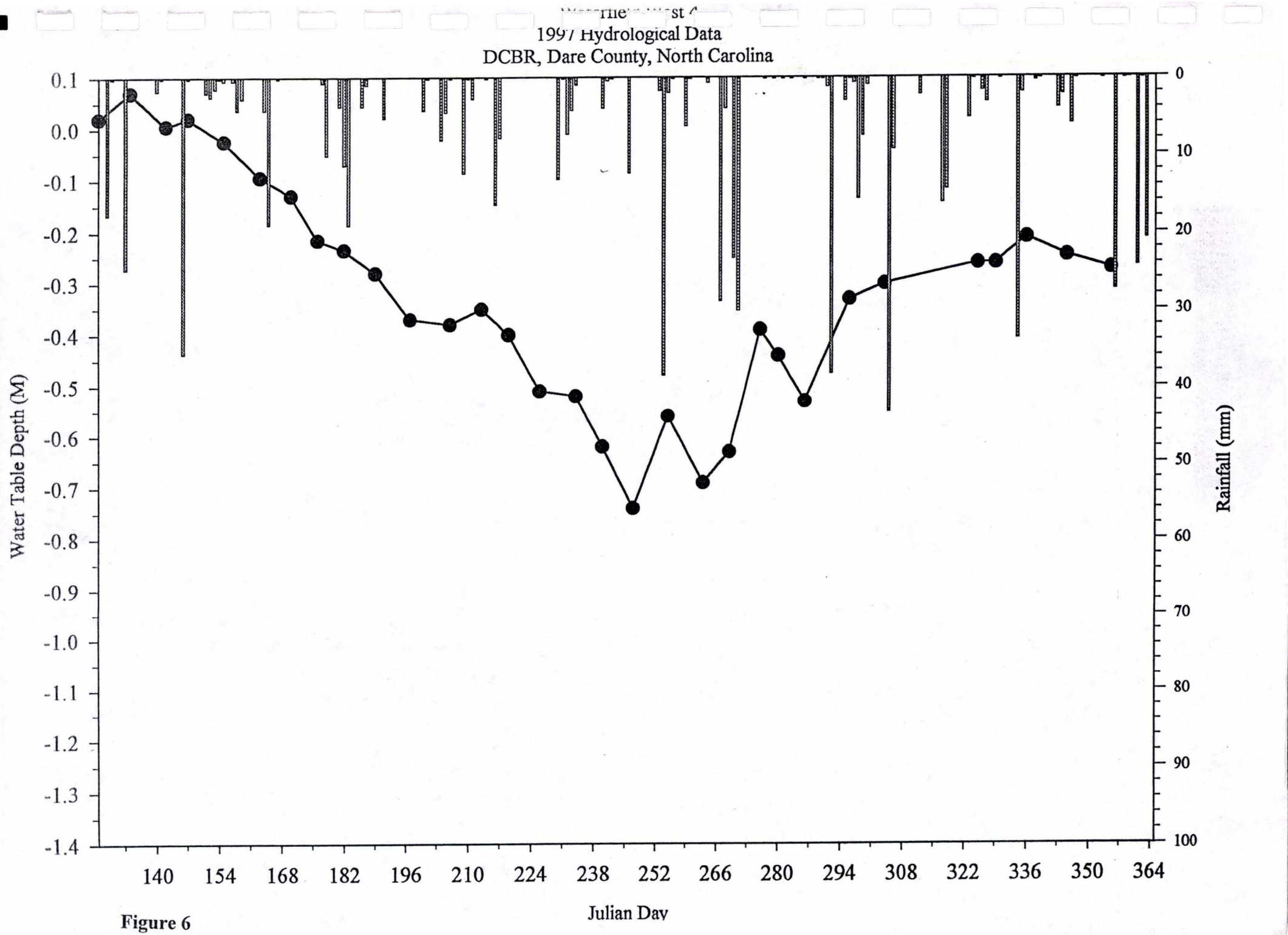
294
308
322
336
350
364

Figure 5


1997 Hydrological Data
DCBR, Dare County, North Carolina
Water Table Depth (M)
Rainfall (mm)
Julian Day
0.1
0.0
-0.1
-0.2
-0.3
-0.4
-0.5
-0.6
-0.7
-0.8
-0.9
-1.0
-1.1
-1.2
-1.3
-1.4
0
10
20
30
40
50
60
70
80
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308
322
336
350
364

Figure 6

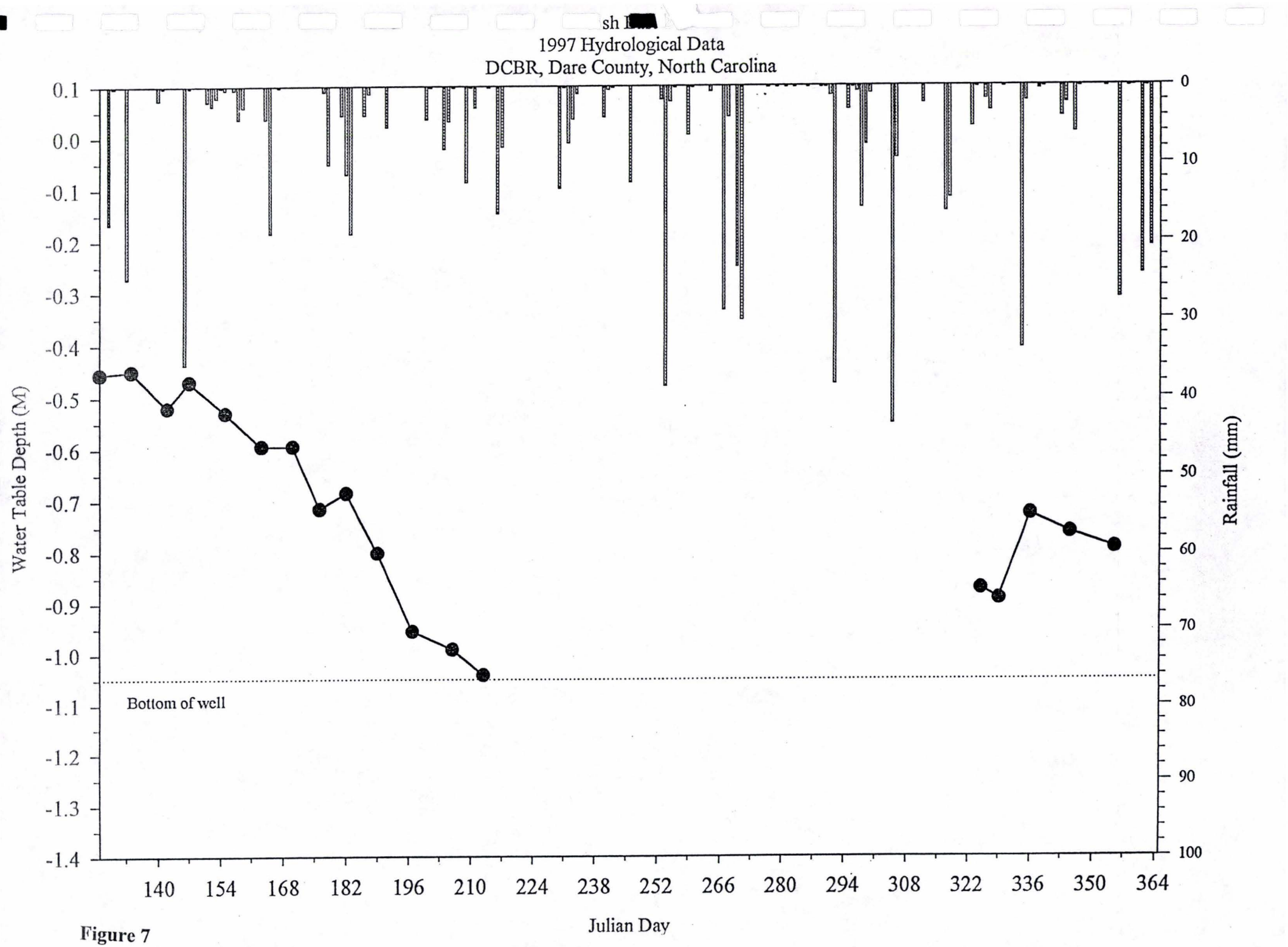
1997 Hydrological Data
DCBR, Dare County, North Carolina
Water Table Depth (M)
Rainfall (mm)
Julian Day
Bottom of well
0.1
0.0
-0.1
-0.2
-0.3
-0.4
-0.5
-0.6
-0.7
-0.8
-0.9
-1.0
-1.1
-1.2
-1.3
-1.4
0
10
20
30
40
50
60
70
80
90
100
140
154
168
182
196
210
224
238
252
266
280
294
308
322
336
350
364

Figure 7

Even when comparing wells with large differences in water table depth, the rates of change were similar for the early part of the summer. For example, compare AE2 (Figure 7) withWW4 (Figure 6), the extremes of water depth across the blocks, where the difference in water table depth averaged about 50 cm. The rates of water table decline were similar until about JD 193 (July 12) and then the hydrographs diverged with the rate of water table decline at AE2 increasing. This pattern is indicative of several factors. Firstly, there is likely some lateral recharge toward WW4 from the surrounding area. The water table at that well was consistently closer to the surface than at any other, indicating that it is in a topographic low. That conclusion is supported by the elevation data that show the northwest corner of Waterfield block is slightly down gradient from the remainder of the block. The increasing rate of water table decline at AE2 as the water table depth increased is indicative of two factors:

- the trees are continuing to withdraw water as the water table approaches 1 m in depth, via either small roots growing downward or being produced on large sinker roots and upward flux in response to the high potential gradient produced by ET at the top of the muck layer
- much lower available water content in the lower part of the organic layer – the more highly decomposed sapric material at the bottom of the organic layer has very low available water content as does the clayey mineral soil beneath it

The decline in water table depth during the summer has no significant lateral drainage component, particularly when the water levels in the ditches have declined sufficiently to reduce the hydraulic heads over the control structures to zero. As noted above, the roadside ditches are thought to have very little impact on runoff from the study blocks. There is no indication of a significant drainage effect when comparing well 1 (about 10 ft from the ditch) with well 2 (250 ft from the ditch) and 3 (500 ft from the ditch) on the transects that begin at a roadside ditch. Compare: WE1 vs. WE2 vs. WE3 (Appendix 6); WW1 vs. WW2 vs. WW3 (Appendix 6); AE1 vs. AE2 vs. AE3 (Appendix 5); or AW1 vs. AW2 vs. AW3 (Appendix 5).

There was also a period of recharge from the ditches into the soil in late summer. For those comparison sets of hydrographs where the water table did not fall below the bottoms of the wells in August (WE1:WE2:WE3, WW1:WW2:WW3, and AW1:AW2:AW3), the water table in well 1 remained closer to the soil surface than in wells 2 and 3. That pattern became apparent when checking the water table depths in July and early August. So, to specifically check that water table gradient, a well was installed in the ditch adjacent to Faircloth Road at the eastern end of Waterfield block. The water table elevations in the ditch well and wells 1 and 2 are shown in Table 8 for days 234 – 325 (August 22 – November 22). The water table in well 1, located about 3 m from the ditch, stayed at the same elevation as that in the ditch while the elevation in well 2 was 0.3-0.5 m lower until recharge began in mid-October. That behavior indicates that the water level in the roadside ditch was higher than in the soil adjacent to it and a hydraulic gradient from the ditch to the soil was present for much of the late summer-early fall period. Because the water in most of the ditches was heavily shaded, the ET rates were lower during the summer in the road side ditches than from the adjacent stands where ET rates were at potential probably until late July, or possibly later, depending on the rates of upward flux and deep root proliferation. Also, the available soil water in the sapric organic layer is quite low, so a centimetre of ET in the stand decreases the water table level much more than a centimetre of ET from the ditch.

Table 8. Relative water table elevations (cm) in Waterfield East Ditch (west side of Faircloth Road) and wells Waterfield East 1 and 2.

Julian Day	WED	WE1	WE2
234	168	168	131
240	158	159	<131
247	164	163	<131
255	169	169	131
263	167	176	<131
269	167	163	<131
276	172	172	<131
280	164	166	152
286	159	159	135
304	177	184	
325	180		181

The fact that water levels in road side ditches are not necessarily representative of the water table levels in the stand at some distance from the ditch is very important for fire managers to consider in estimating fire danger in an organic soil system. There are two different scenarios that may occur:

- No control structures in ditches and relatively high drainage gradients. In the low ET wet season, the water table level is likely closer to the surface in the stand at some distance from the ditch (closer to the surface) than in and near the ditch due to the drainage effect. During the late summer and early fall dry period of high ET, the water table level is likely lower in the stand at some distance from the ditch (deeper from the surface) than in and near the ditch.
- Control structures in ditches and low or no drainage gradients. In the low ET wet season, the water table level is likely about the same in the stand at some distance from the ditch as in and near the ditch. During the late summer and early fall dry period of high ET, the water table level is likely lower in the stand at some distance from the ditch (deeper from the surface) than in and near the ditch.

That the water table depth continued to increase rapidly during the relatively high rainfall of July (101 mm) indicates that ET rates are usually limited by available water supply under normal late summer rainfall.

It is also quite interesting to note how the water table in different wells responded to the large rainfall event (39 mm) on JD 254 (September 11). Where the water table was still within the bottom of a well and was within 1 m of the surface, the water table rose 10-20 cm in response to that event. At many wells where the water table had been below the bottom of the well for some time (probably greater than 1 m deep in many cases), the water table did not rise into the well following that event. In such cases, there was more than enough available soil storage for that rainfall in the upper meter of the organic soil.

Note also the response of the water level in the piezometers that had been installed prior to that event. In some instances, there was no water table response in the well and the level in the adjacent piezometer continued to slowly decline in the week following the day 254 event (due to

upward flux) and then rose in response to additional rain of 87 mm on days 267-271 (Figures 8-11). In other well/piezometer pairs there was no water table response to the series of rainfall events in the well but an immediate rise in the water level in the piezometer in response to the first and then succeeding rainfall events (Figures 12-15). This behavior resulted from another type of recharge from the ditches, the hydraulic gradient being expressed through the sand beneath the clay layer. With 126 mm of rainfall over two weeks, road runoff resulted in a significant increase in the water level in the ditches and the hydraulic gradient through the sand resulted in recharge upward into the clay layer in a zone within a short distance of the road. During the recharge period, the changes in the water level in the piezometers, either up or down were smaller than in the adjacent wells. This indicates that water was moving more slowly in the vertical direction through the clay layer than through the upper zone of the organic layer.

The pattern of soil water recharge in the fall varied with the depth of the water table in early September. Where the water table was within one meter of the surface, there generally was a water table response to the rain in September and then a decline during a 3-week dry period in early October (e.g., Figure 6). A rainfall of 39 mm on day 292 (October 19) began a consistent recharge of soil moisture and concomitant gradual rise in the water table level. A week of warm sunny weather in mid-December resulted in a slight decline in the water table level and full recharge probably was not completed until late January. At wells where the water table was well below one meter in early September, there was no water table response to the rain in September (e.g., Figures 8, 10 and 12). At such locations, significant recharge of the soil and subsequent rise of the water table did not occur until late October and the water table was still about 40-50 cm deep in late December. The hydrographs of Appendix 7 that contain segments of datalogger data show essentially the same information as the hydrographs of manual readings except that the hydrograph line shows the short-term variability that is missed by periodic manual measurements. This is shown clearly by the water table behavior in well AN1 (Figure 16). The high "spikes" of rapid water table rise and fall when the water table was below one meter in September were likely due to "preferential flow". That is a term that refers to rapid unsaturated flow through large pores such as root channels when the soil matrix is unsaturated. The rapid decline of that spike is likely a combination of upward flux and water in the well being adsorbed by the organic soil.

The seasonal pattern of the water table depth at the high pocosin and low pocosin fuel sampling sites was similar to that in the pond pine woodland except that the water table was much closer to the surface throughout the study period (Figures 17-20).

The water level recorders provide the capability to illustrate short-term, highly detailed hydrographs of water table variation and some examples of such hydrographs are included in Appendix 8. The first group of hydrographs show a four-day rain-free period in July. Figures 21 and 22 show two examples (note that vertical scales vary). The narrow vertical scale of Figure 22 shows the diurnal variation of ET in the water table level. Note also the differences in the amount of water table decline among the three wells over the three-day period. The water table in well WW3 began at a depth of 350 mm and declined about 40 mm. The water table in well AW3 began at a depth of 415 mm and declined about 55 mm. The water table in well WN3 began at a depth of 465 mm and declined about 50 mm. The total PET over that period was 16 mm.

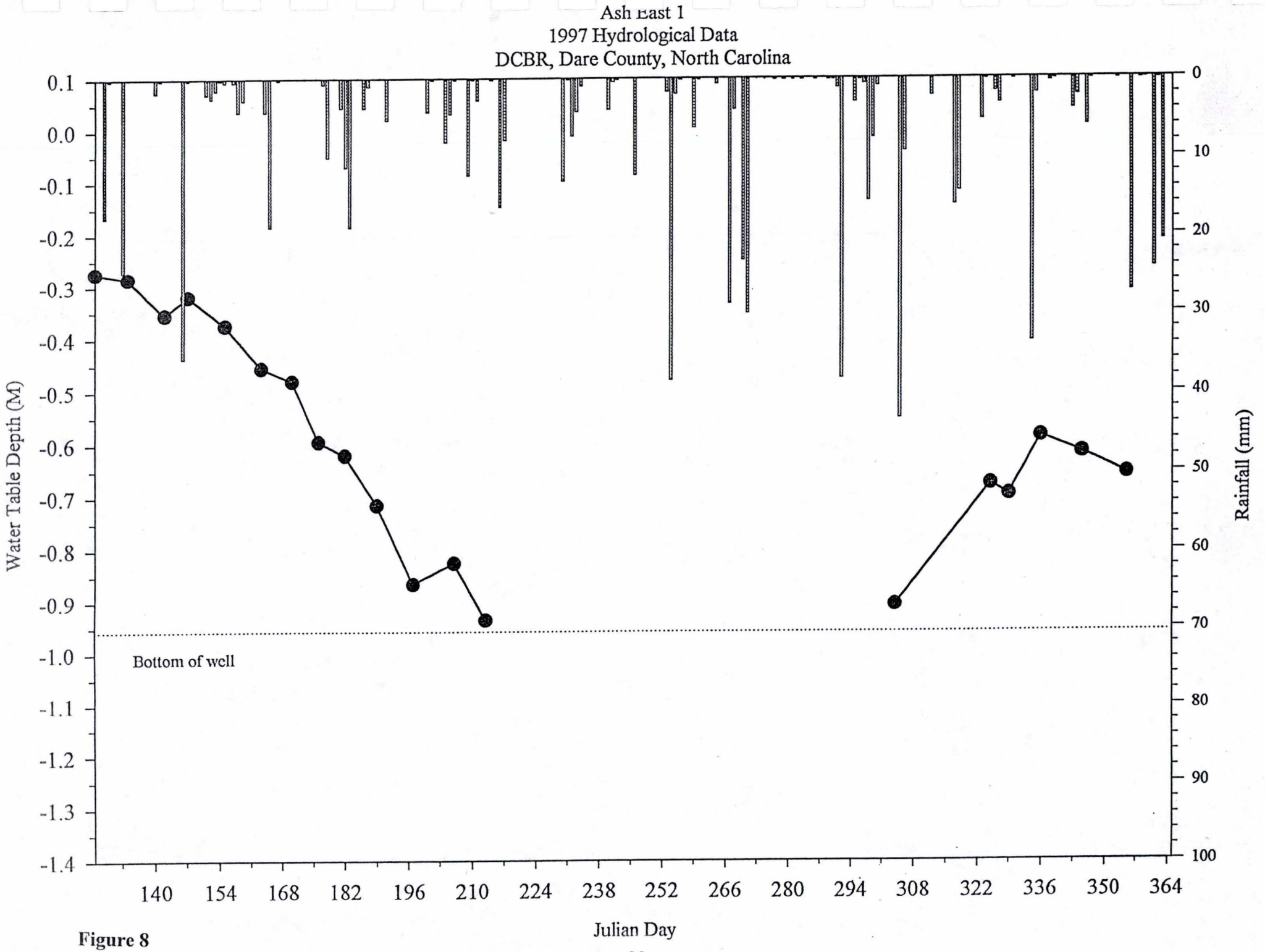
Ash East 1
1997 Hydrological Data
DCBR, Dare County, North Carolina
Water Table Depth (M)
Rainfall (mm)
Bottom of well
Julian Day
0.1
0.0
-0.1
-0.2
-0.3
-0.4
-0.5
-0.6
-0.7
-0.8
-0.9
-1.0
-1.1
-1.2
-1.3
-1.4
0
10
20
30
40
50
60
70
80
90
100
140
154
168
182
196
210
224
238
252
266
280
294
308
322
336
350
364

Figure 8

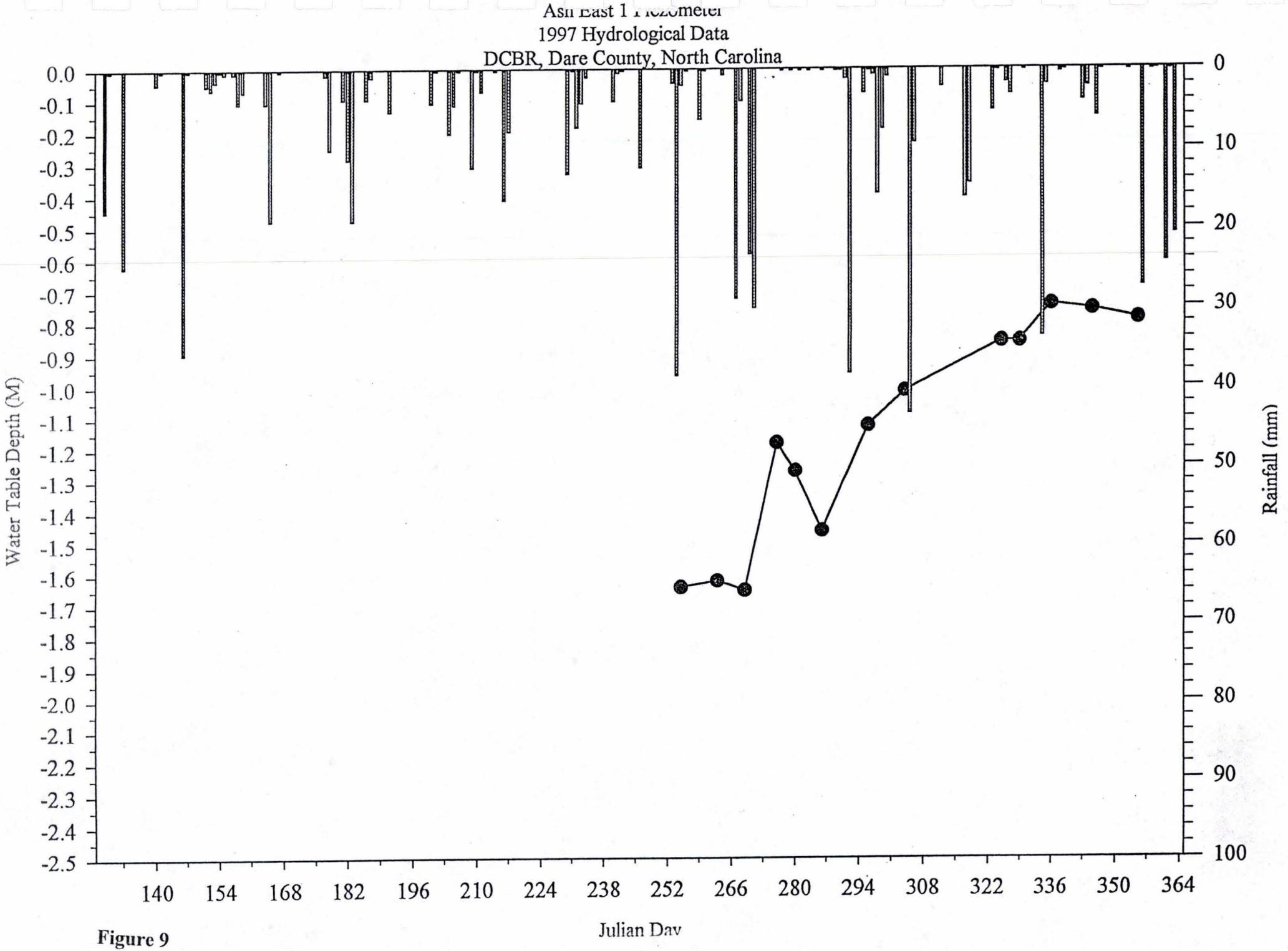
Ash East 1 Piezometer
1997 Hydrological Data
DCBR, Dare County, North Carolina
Water Table Depth (M)
0.0
-0.1
-0.2
-0.3
-0.4
-0.5
-0.6
-0.7
-0.8
-0.9
-1.0
-1.1
-1.2
-1.3
-1.4
-1.5
-1.6
-1.7
-1.8
-1.9
-2.0
-2.1
-2.2
-2.3
-2.4
-2.5
Rainfall (mm)
0
10
20
30
40
50
60
70
80
90
100
140
154
168
182
196
210
224
238
252
266
280
294
308
322
336
350
364
Julian Day

Figure 9

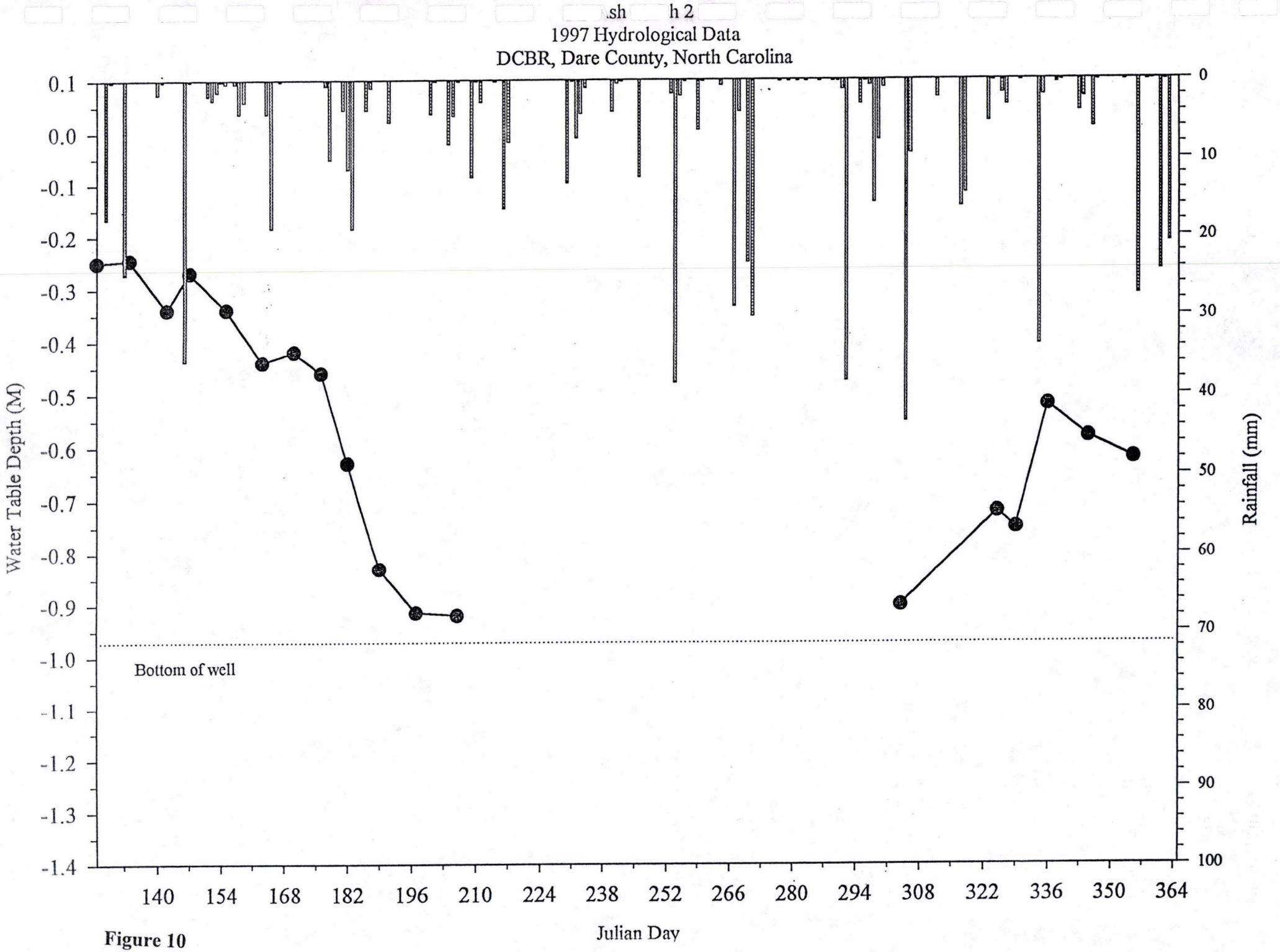
1997 Hydrological Data
DCBR, Dare County, North Carolina
Water Table Depth (M)
Rainfall (mm)
Bottom of well
Julian Day
0.1
0.0
-0.1
-0.2
-0.3
-0.4
-0.5
-0.6
-0.7
-0.8
-0.9
-1.0
-1.1
-1.2
-1.3
-1.4
0
10
20
30
40
50
60
70
80
90
100
140
154
168
182
196
210
224
238
252
266
280
294
308
322
336
350
364

Figure 10

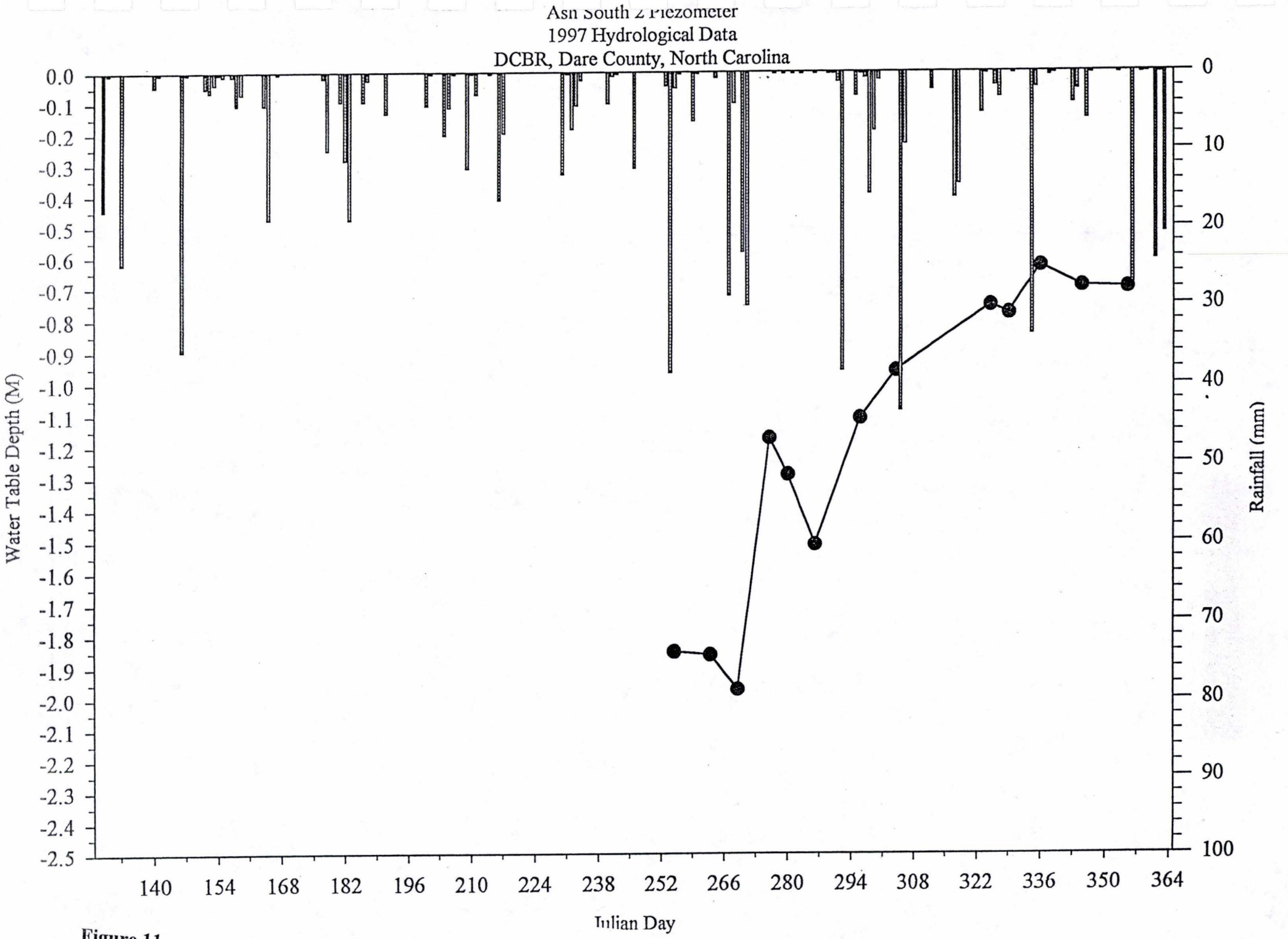
Asn South 2 Piezometer
1997 Hydrological Data
DCBR, Dare County, North Carolina
Water Table Depth (M)
0.0
-0.1
-0.2
-0.3
-0.4
-0.5
-0.6
-0.7
-0.8
-0.9
-1.0
-1.1
-1.2
-1.3
-1.4
-1.5
-1.6
-1.7
-1.8
-1.9
-2.0
-2.1
-2.2
-2.3
-2.4
-2.5
Rainfall (mm)
0
10
20
30
40
50
60
70
80
90
100
140
154
168
182
196
210
224
238
252
266
280
294
308
322
336
350
364
Julian Day

Figure 11

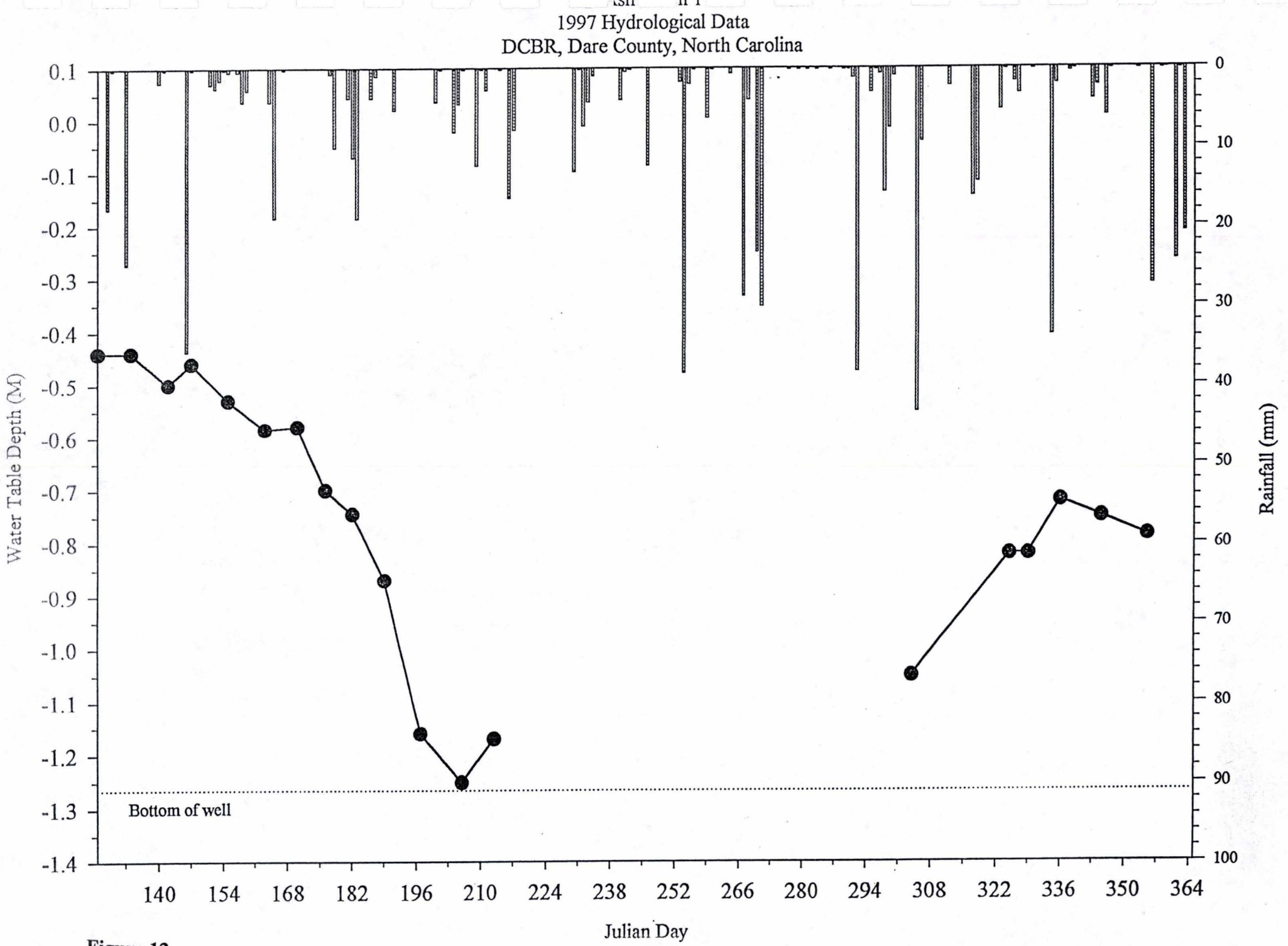
1997 Hydrological Data
DCBR, Dare County, North Carolina
Water Table Depth (M)
Rainfall (mm)
Julian Day
Bottom of well
0.1
0.0
-0.1
-0.2
-0.3
-0.4
-0.5
-0.6
-0.7
-0.8
-0.9
-1.0
-1.1
-1.2
-1.3
-1.4
0
10
20
30
40
50
60
70
80
90
100
140
154
168
182
196
210
224
238
252
266
280
294
308
322
336
350
364

Figure 12

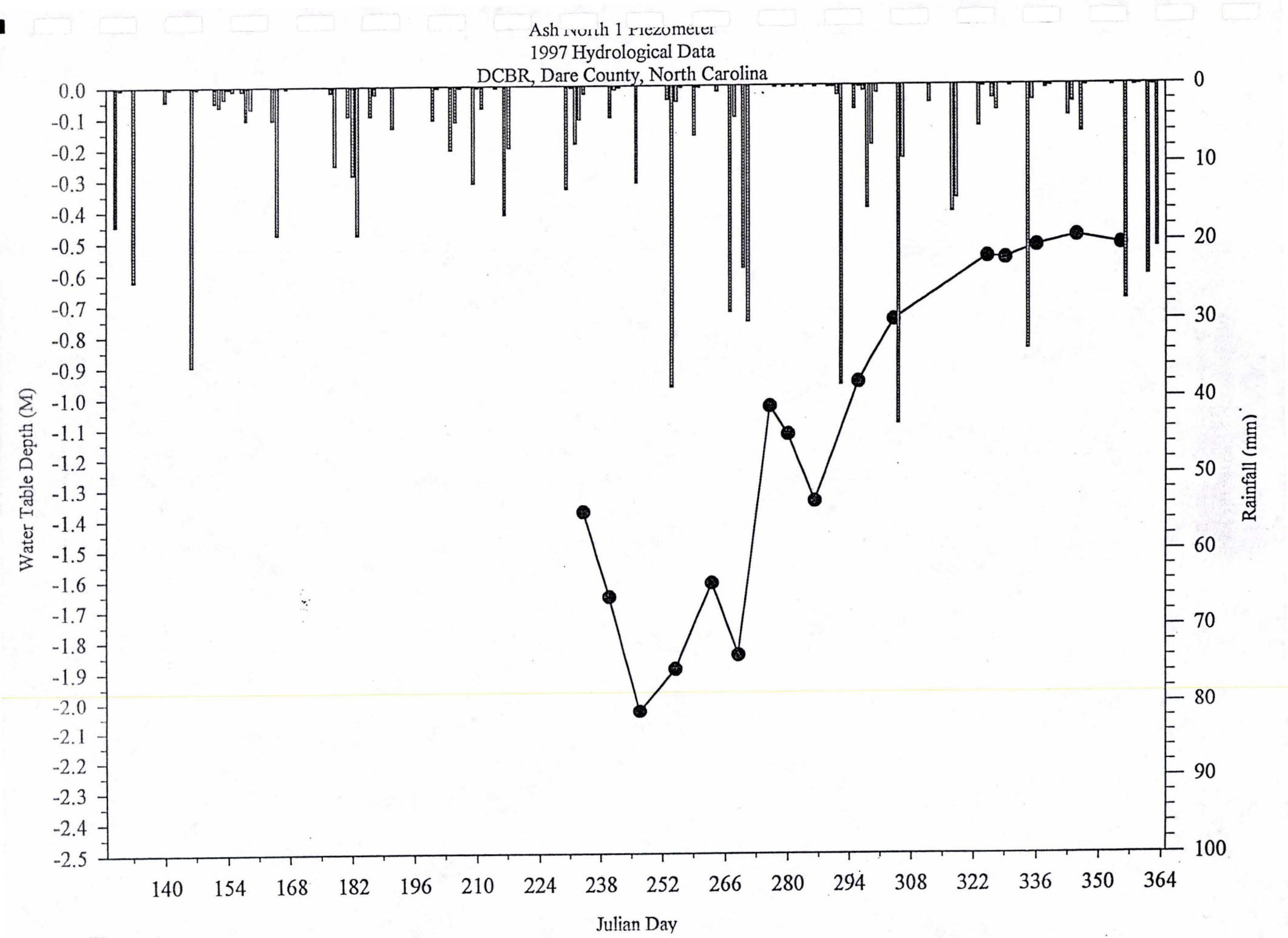
Ash North 1 Piezometer
1997 Hydrological Data
DCBR, Dare County, North Carolina
Water Table Depth (M)
0.0
-0.1
-0.2
-0.3
-0.4
-0.5
-0.6
-0.7
-0.8
-0.9
-1.0
-1.1
-1.2
-1.3
-1.4
-1.5
-1.6
-1.7
-1.8
-1.9
-2.0
-2.1
-2.2
-2.3
-2.4
-2.5
Rainfall (mm)
0
10
20
30
40
50
60
70
80
90
100
140
154
168
182
196
210
224
238
252
266
280
294
308
322
336
350
364
Julian Day

Figure 13

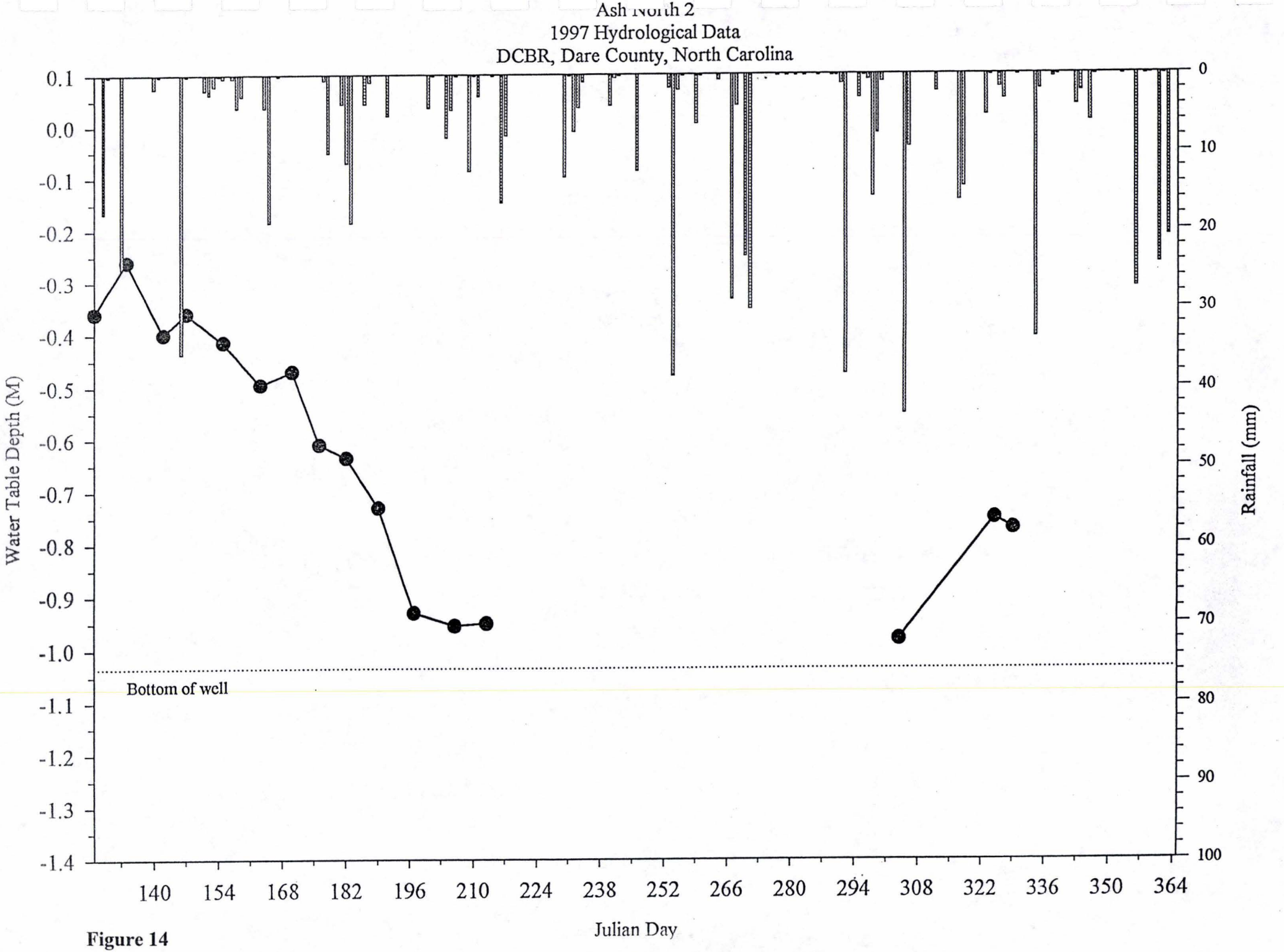
Ash North 2
1997 Hydrological Data
DCBR, Dare County, North Carolina
Water Table Depth (M)
0.1
0.0
-0.1
-0.2
-0.3
-0.4
-0.5
-0.6
-0.7
-0.8
-0.9
-1.0
-1.1
-1.2
-1.3
-1.4
Bottom of well
Rainfall (mm)
0
10
20
30
40
50
60
70
80
90
100
140
154
168
182
196
210
224
238
252
266
280
294
308
322
336
350
364
Julian Day

Figure 14

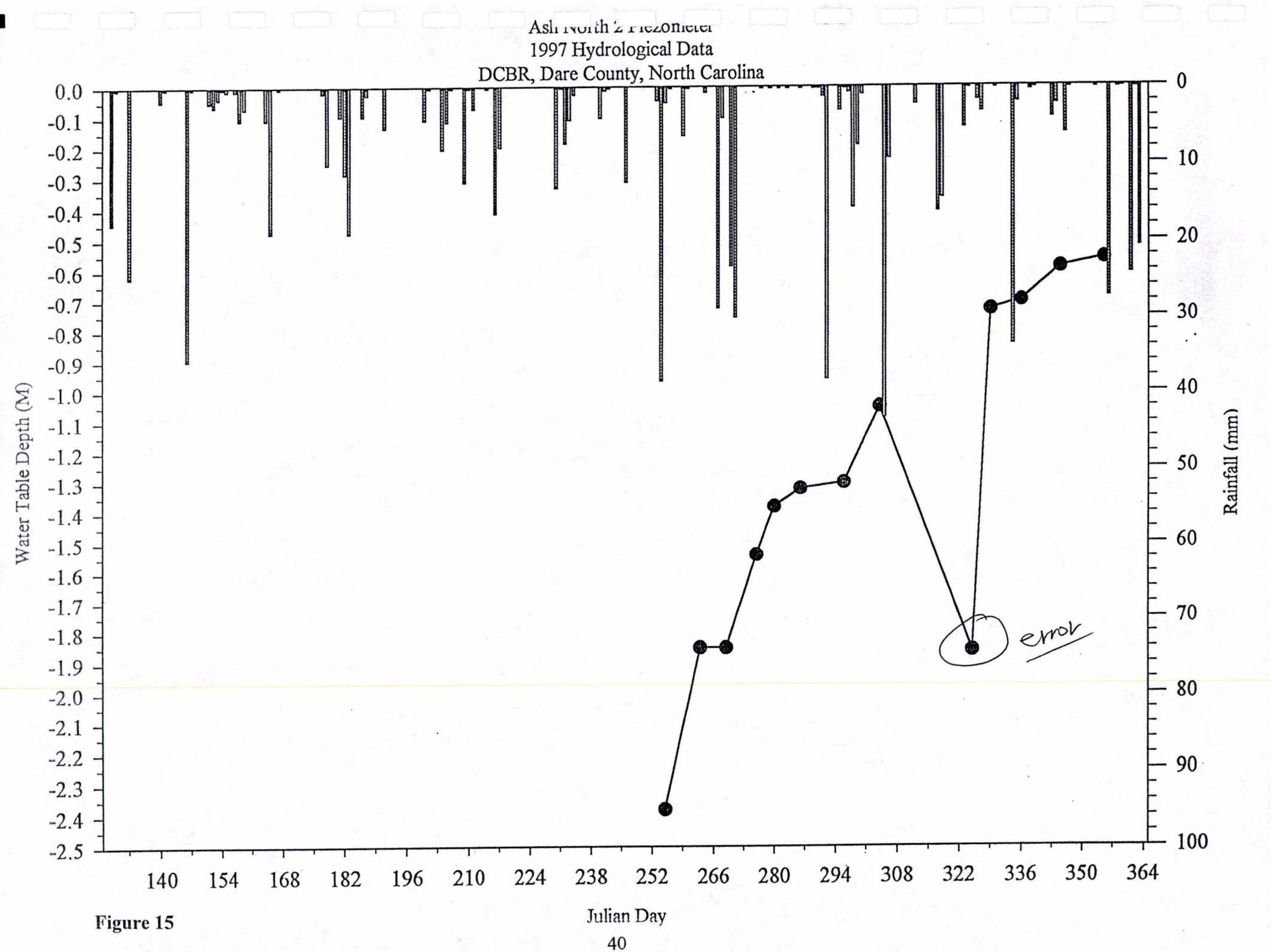
Ash North 2 Piezometer
1997 Hydrological Data
DCBR, Dare County, North Carolina
Water Table Depth (M)
0.0
-0.1
-0.2
-0.3
-0.4
-0.5
-0.6
-0.7
-0.8
-0.9
-1.0
-1.1
-1.2
-1.3
-1.4
-1.5
-1.6
-1.7
-1.8
-1.9
-2.0
-2.1
-2.2
-2.3
-2.4
-2.5
Rainfall (mm)
0
10
20
30
40
50
60
70
80
90
100
140
154
168
182
196
210
224
238
252
266
280
294
308
322
336
350
364
Julian Day
error

Figure 15

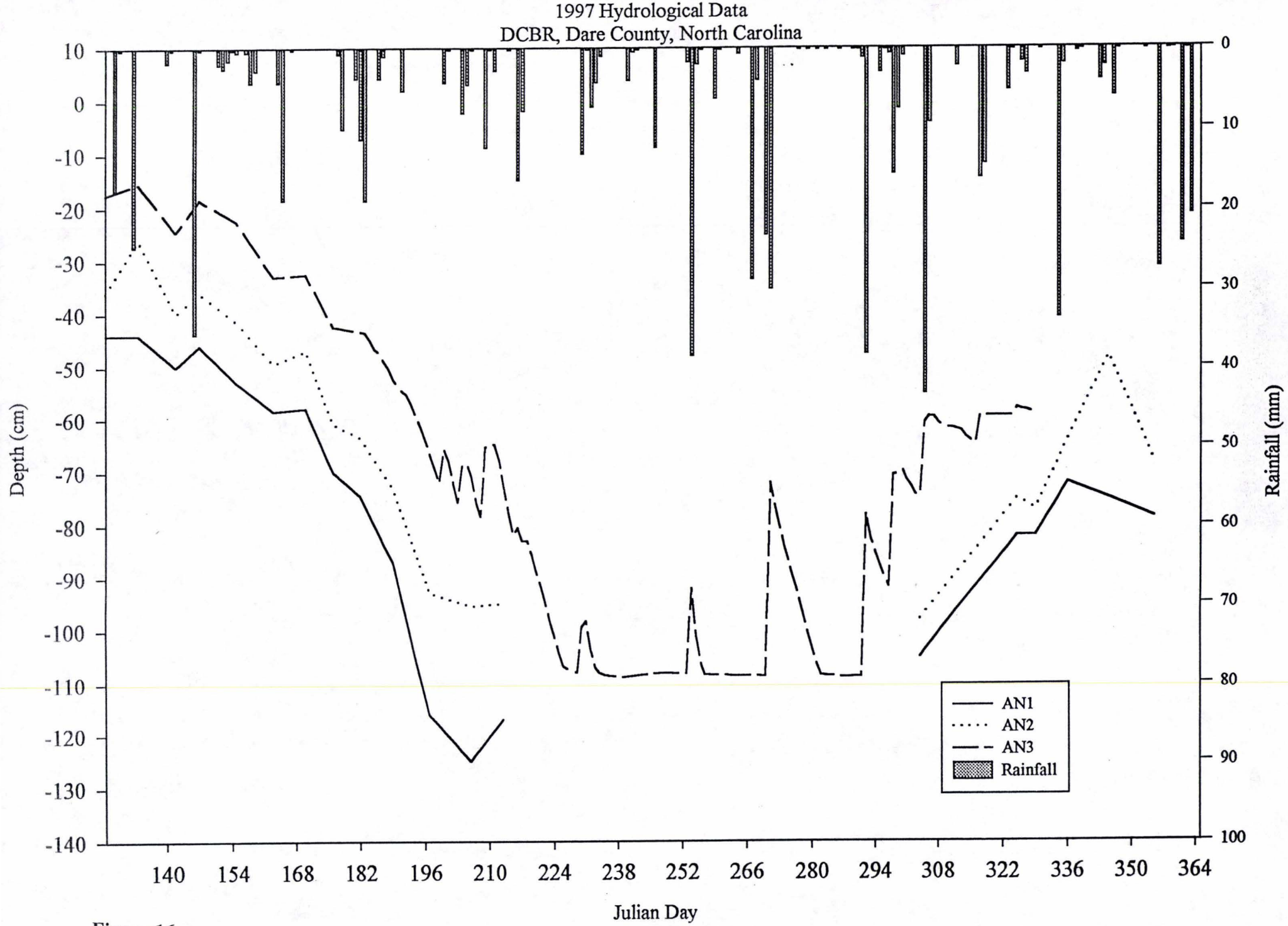
1997 Hydrological Data
DCBR, Dare County, North Carolina
Depth (cm)
Rainfall (mm)
Julian Day
AN1
AN2
AN3
Rainfall

Figure 16

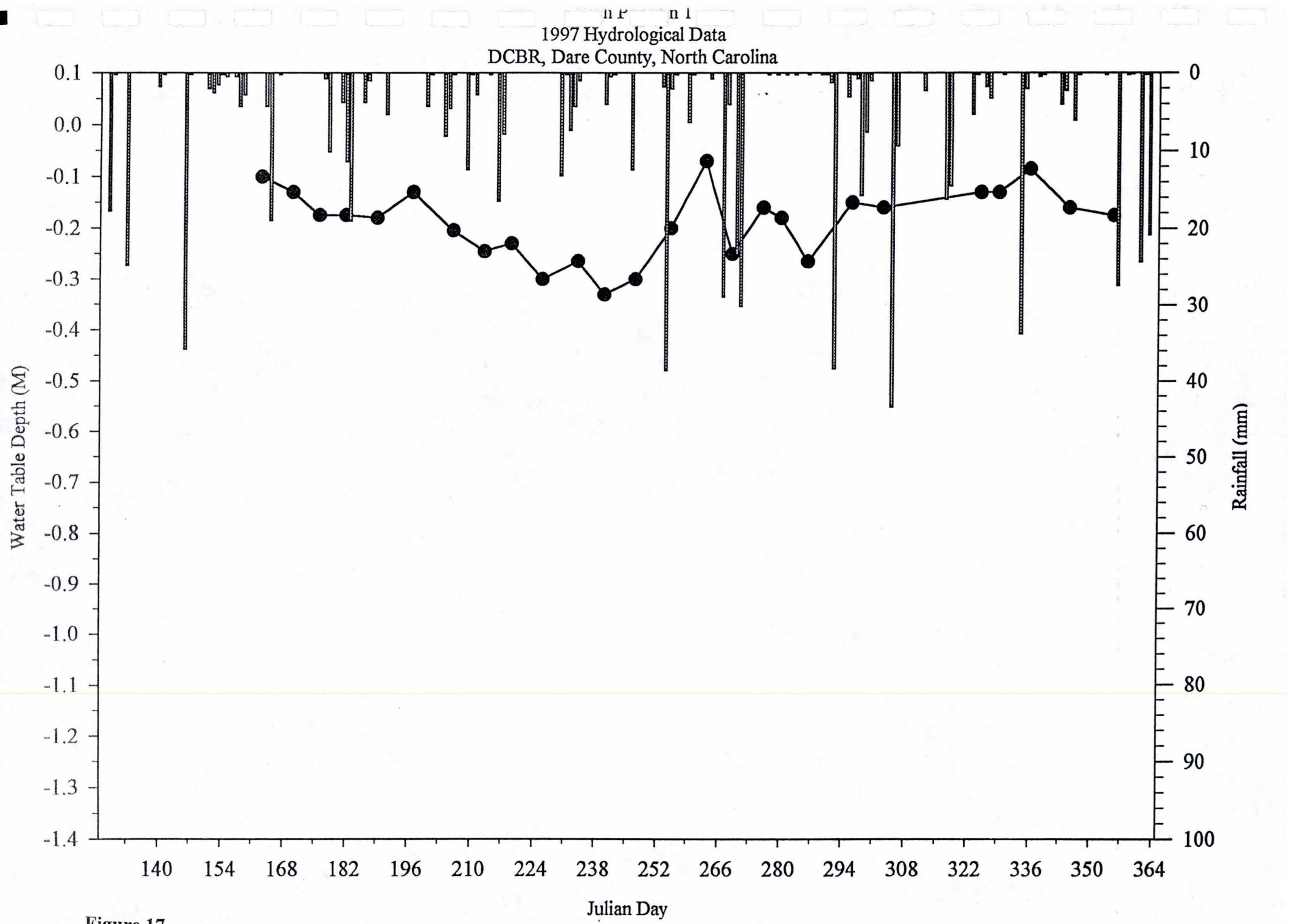
1997 Hydrological Data
DCBR, Dare County, North Carolina
Water Table Depth (M)
0.1
0.0
-0.1
-0.2
-0.3
-0.4
-0.5
-0.6
-0.7
-0.8
-0.9
-1.0
-1.1
-1.2
-1.3
-1.4
Rainfall (mm)
0
10
20
30
40
50
60
70
80
90
100
140
154
168
182
196
210
224
238
252
266
280
294
308
322
336
350
364
Julian Day

Figure 17

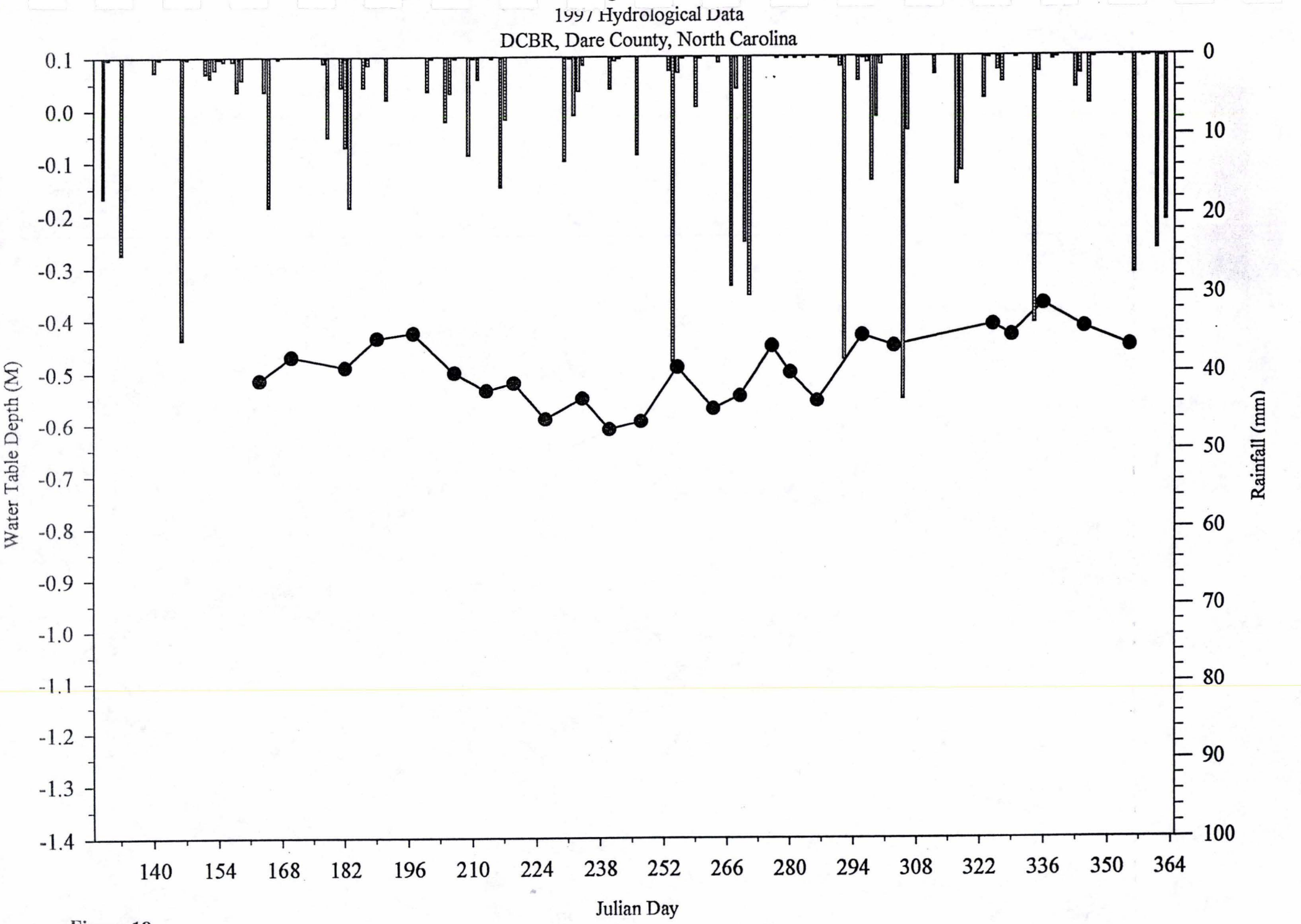
1997 Hydrological Data
DCBR, Dare County, North Carolina
Water Table Depth (M)
0.1
0.0
-0.1
-0.2
-0.3
-0.4
-0.5
-0.6
-0.7
-0.8
-0.9
-1.0
-1.1
-1.2
-1.3
-1.4
Rainfall (mm)
0
10
20
30
40
50
60
70
80
90
100
140
154
168
182
196
210
224
238
252
266
280
294
308
322
336
350
364
Julian Day

Figure 18

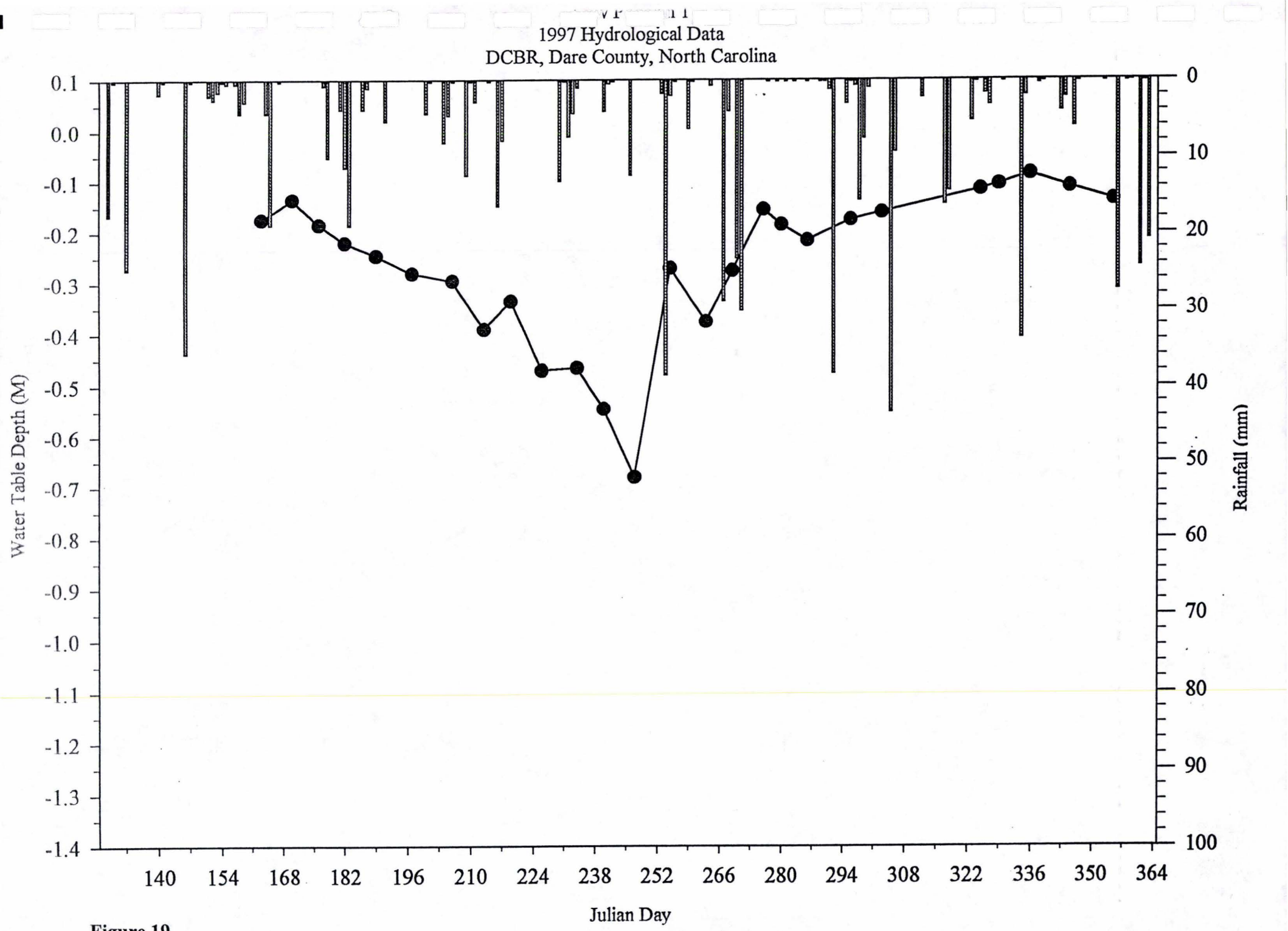
1997 Hydrological Data
DCBR, Dare County, North Carolina
Water Table Depth (M)
0.1
0.0
-0.1
-0.2
-0.3
-0.4
-0.5
-0.6
-0.7
-0.8
-0.9
-1.0
-1.1
-1.2
-1.3
-1.4
Rainfall (mm)
0
10
20
30
40
50
60
70
80
90
100
140
154
168
182
196
210
224
238
252
266
280
294
308
322
336
350
364
Julian Day

Figure 19

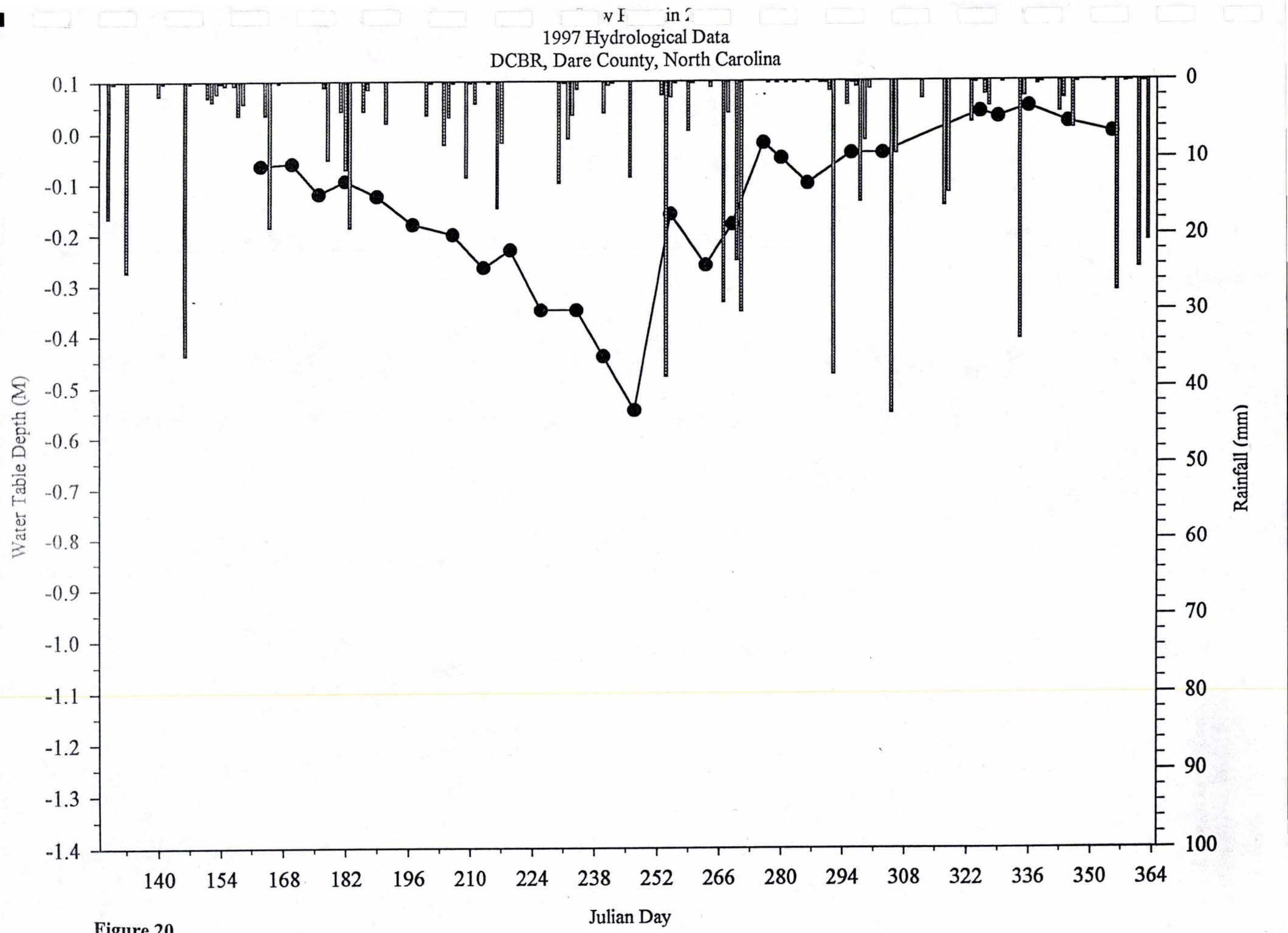
1997 Hydrological Data
DCBR, Dare County, North Carolina
Water Table Depth (M)
0.1
0.0
-0.1
-0.2
-0.3
-0.4
-0.5
-0.6
-0.7
-0.8
-0.9
-1.0
-1.1
-1.2
-1.3
-1.4
Rainfall (mm)
0
10
20
30
40
50
60
70
80
90
100
140
154
168
182
196
210
224
238
252
266
280
294
308
322
336
350
364
Julian Day

Figure 20

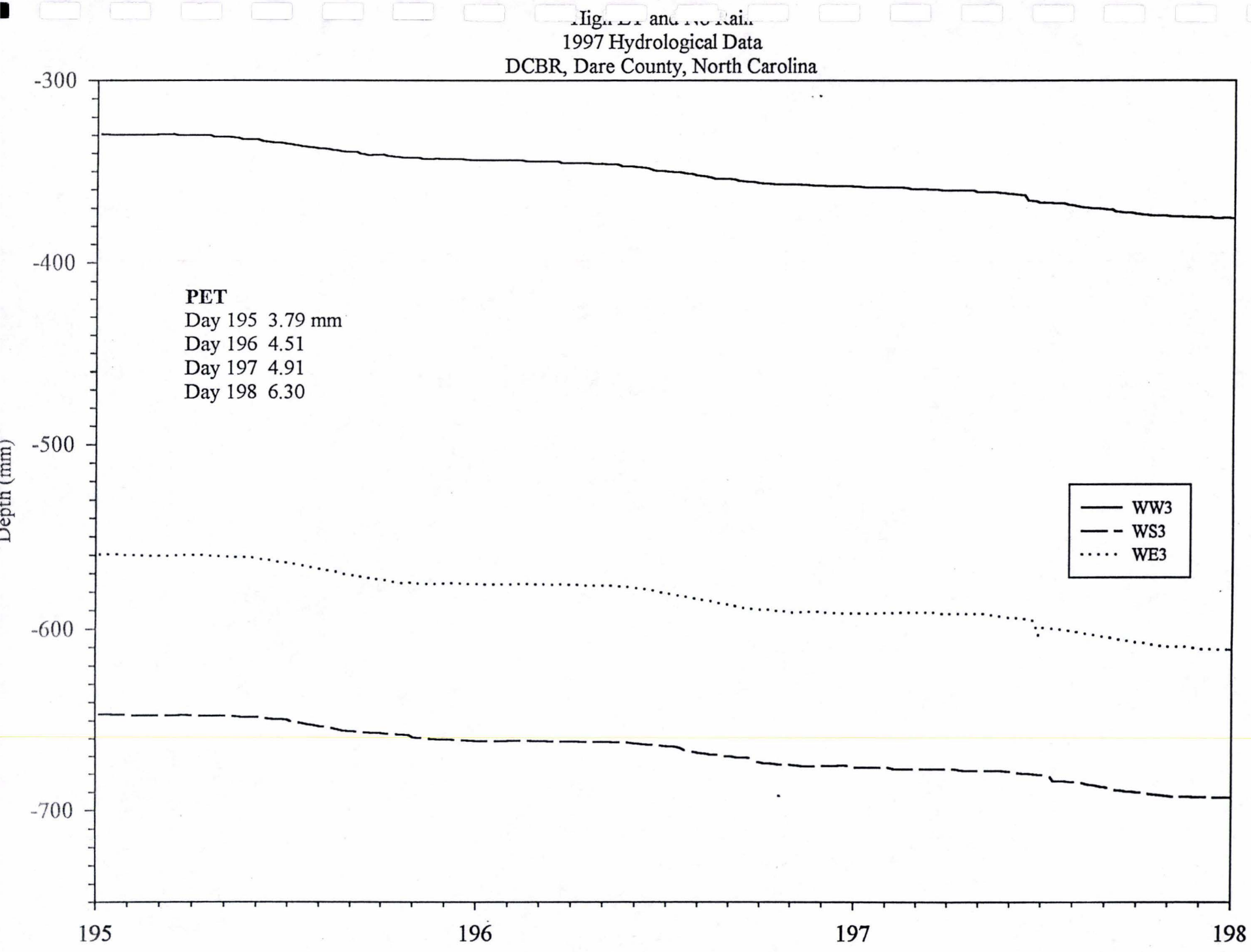
1997 Hydrological Data
DCBR, Dare County, North Carolina
-300
-400
-500
-600
-700
Depth (mm)
PET
Day 195 3.79 mm
Day 196 4.51
Day 197 4.91
Day 198 6.30
WW3
WS3
WE3
195
196
197
198
Julian Day

Figure 21

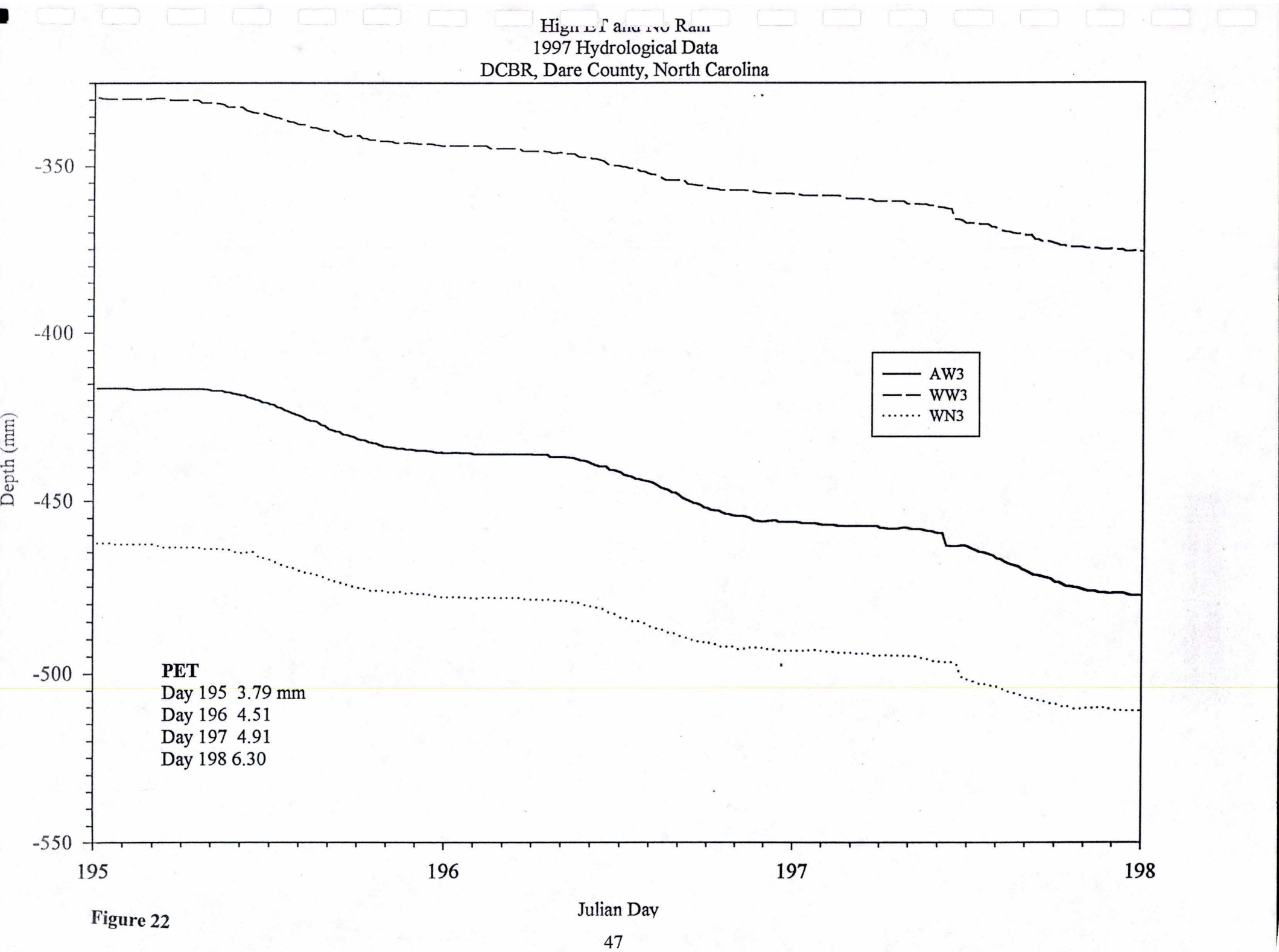
High ET and No Rain
1997 Hydrological Data
DCBR, Dare County, North Carolina
-350
-400
-450
-500
-550
Depth (mm)
AW3
WW3
WN3
PET
Day 195 3.79 mm
Day 196 4.51
Day 197 4.91
Day 198 6.30
195
196
197
198
Julian Day

Figure 22

Short Term Changes

The second set of hydrographs show the varying water table response to a couple of small rainfall events in early August. Examples of two of those charts are shown in Figures 23 and 24. Rainfall of 17 mm resulted in a rise in the water table of about 50 mm where the water table was as deep as 70-90 cm. There was no water table response in a well in which the water table was slightly more than 1 m deep. Another set of charts illustrate in fine detail the anomalous well water response to the 39 mm event of September 12 (Figures 25 and 26). In well WE3, the water table was deeper than 1 m (float was resting on bottom of well). There was a very rapid rise of about 15 cm in the water level in the well and the level immediately began a relatively rapid decline. That behavior is indicative of unsaturated flow entering the well and immediately being absorbed by the soil. Figure 27 shows a recharge event where the water table was at about 1 m depth in well WE2 and 38 mm of rainfall resulted in a much more gradual rise in the water table over a period of more than 12 hours and the water table slowly continued to rise during the next two days. This illustrates some rapid preferential flow and the more slow downward movement of a wetting front.

Spatial Variation of the Water Table Depth

Charts of water table depth transects for each date on which manual water table measurements were made are included in the Appendices. Appendix 9 contains the charts for the Ash east-west transect; Appendix 10 contains the charts for the Waterfield east-west transect and Appendix 11 contains the charts for the north-south Waterfield-Ash transect. Charts of water table elevation transects for the wells for which surface elevation data were available are included in Appendix 16. A relatively wide vertical scale was necessary to accommodate the change in water table depth over the measurement period and retain a standard scale. The well locations on the charts are spaced to scale according to the actual spacing on the ground. A sample of three charts (each of which contains three measurement dates) from each set was selected for detailed review that covers three different times:

- May – water table still near the surface in lower lying areas of the blocks, but decline into summer has begun
- July – intermediate water table depth
- late December – recharge cycle

Ash East-West Transect

Three sample charts of the Ash east-west transect for water table depth are Figures 28-30 and three sample charts for the same time periods of water table elevation are Figures 28A-30A. The water table transects are oriented with well AE1 at the left edge and well BA2 at the right edge. Figures 28 and 28A shows the water table transects for days 127, 134, and 142 (mid-May). Four principal factors influence the variation in water table depth across the Ash block from east to west.

- The general gradient of about 0.3 m in water table depth from well AE1 to well AW1 reflects mainly the surface gradient. There also appears to be a slight upward gradient from east to west in the water table elevation. That is likely due to the fact that ET is withdrawing water from a zone of lower available water per unit of depth on the eastern end of the block than on the western end. When the western end of Ash block is inundated deep enough for water to flow over Beechland Road, very slow flow (due to the low gradient) does occur from east to

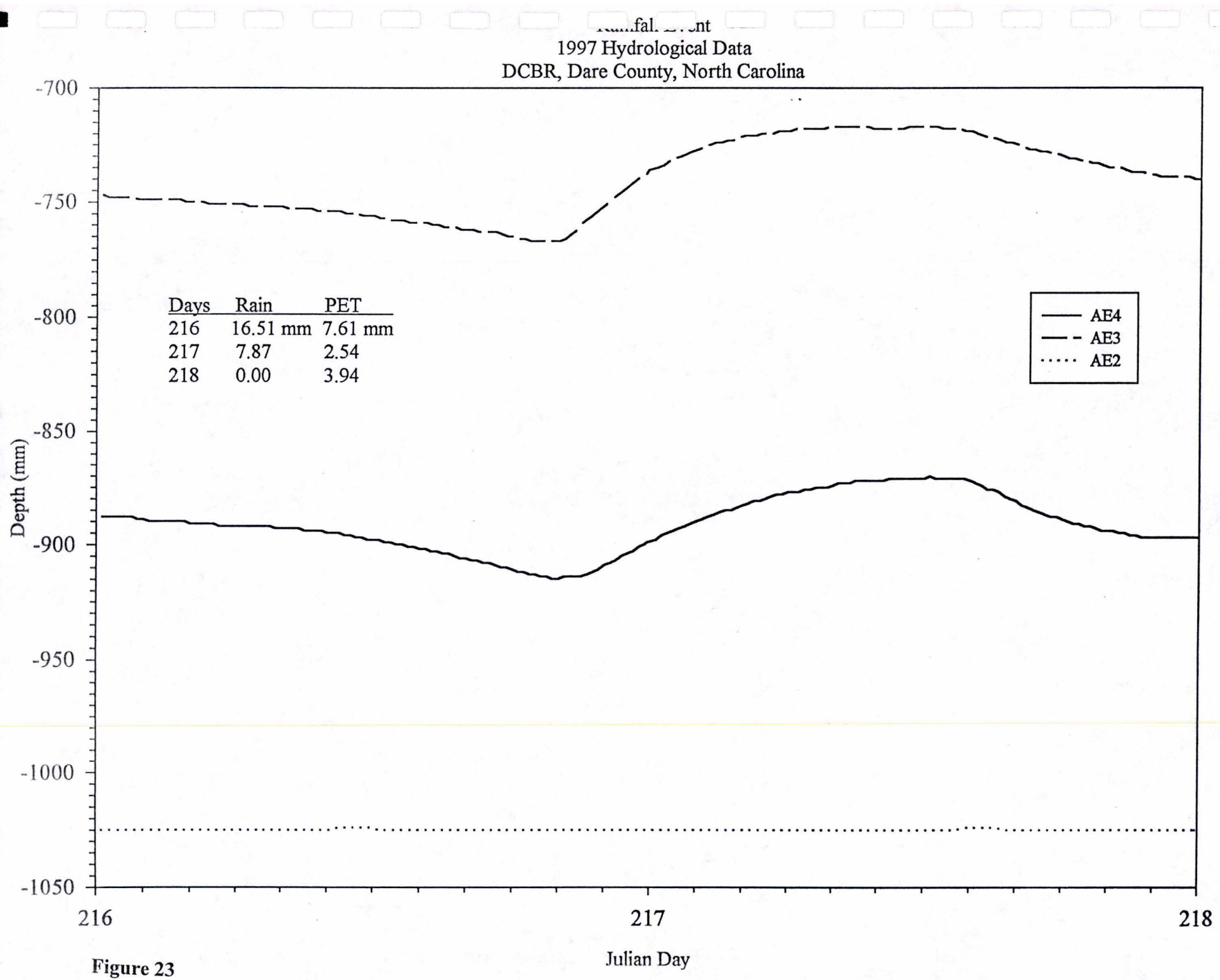
Rainfall Event
1997 Hydrological Data
DCBR, Dare County, North Carolina
-700
-750
-800
-850
-900
-950
-1000
-1050
Depth (mm)
Days Rain PET
216 16.51 mm 7.61 mm
217 7.87 2.54
218 0.00 3.94
AE4
AE3
AE2
216
217
218
Julian Day

Figure 23

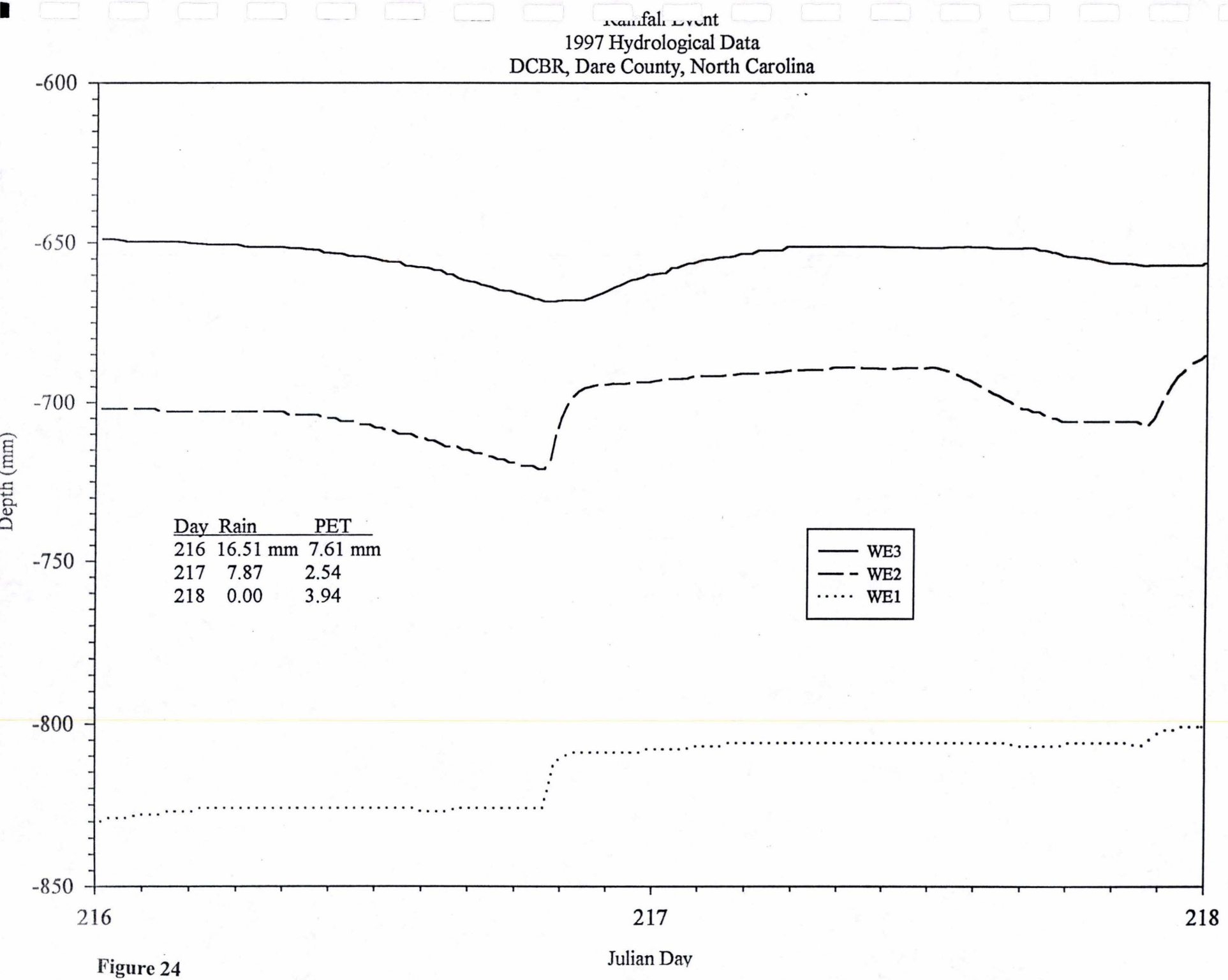
Rainfall Event
1997 Hydrological Data
DCBR, Dare County, North Carolina
-600
-650
-700
-750
-800
-850
Depth (mm)
Day Rain PET
216 16.51 mm 7.61 mm
217 7.87 2.54
218 0.00 3.94
WE3
WE2
WE1
216
217
218
Julian Day

Figure 24

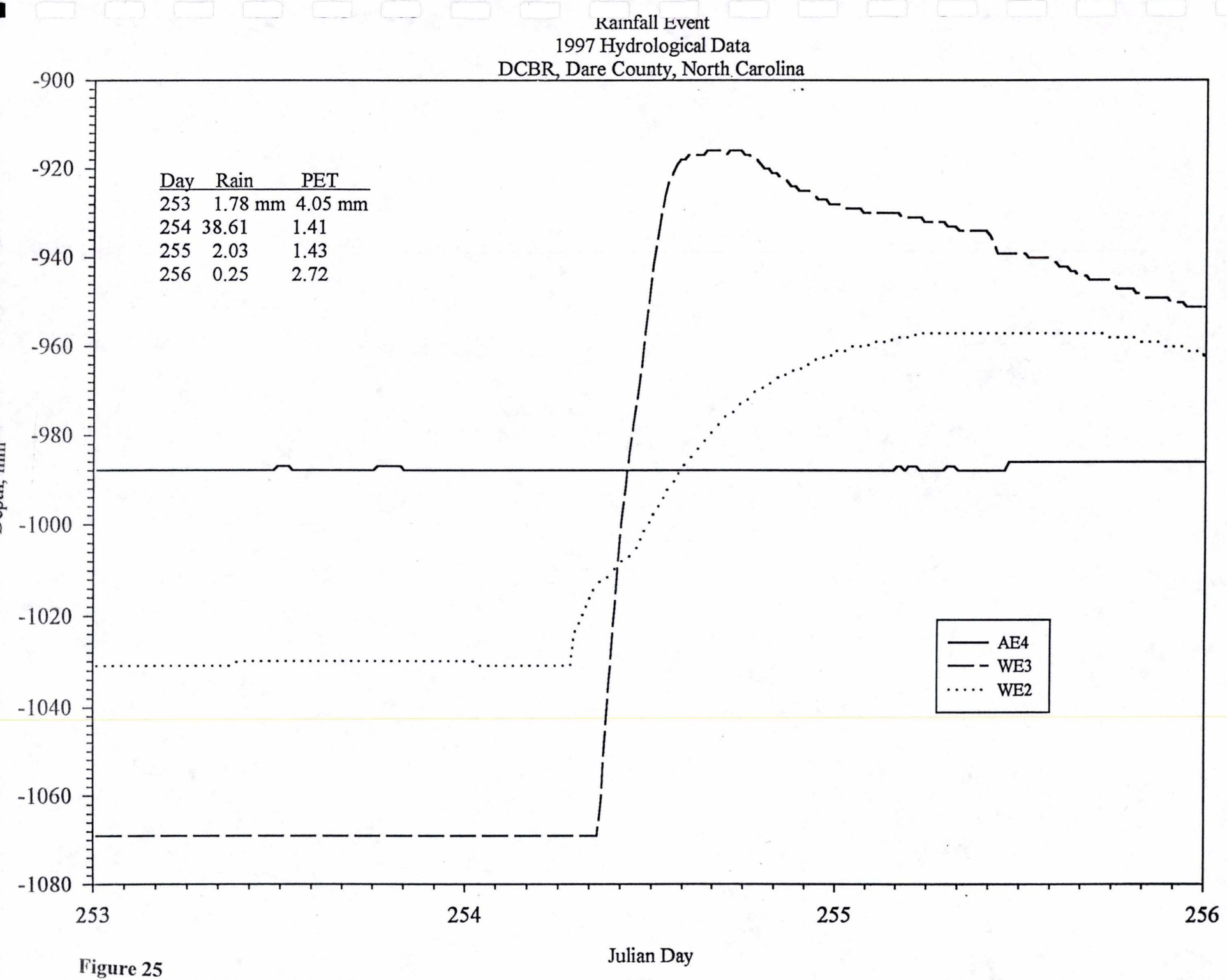
Rainfall Event
1997 Hydrological Data
DCBR, Dare County, North Carolina
Day Rain PET
253 1.78 mm 4.05 mm
254 38.61 1.41
255 2.03 1.43
256 0.25 2.72
-900
-920
-940
-960
-980
-1000
-1020
-1040
-1060
-1080
253
254
255
256
Julian Day
AE4
WE3
WE2

Figure 25

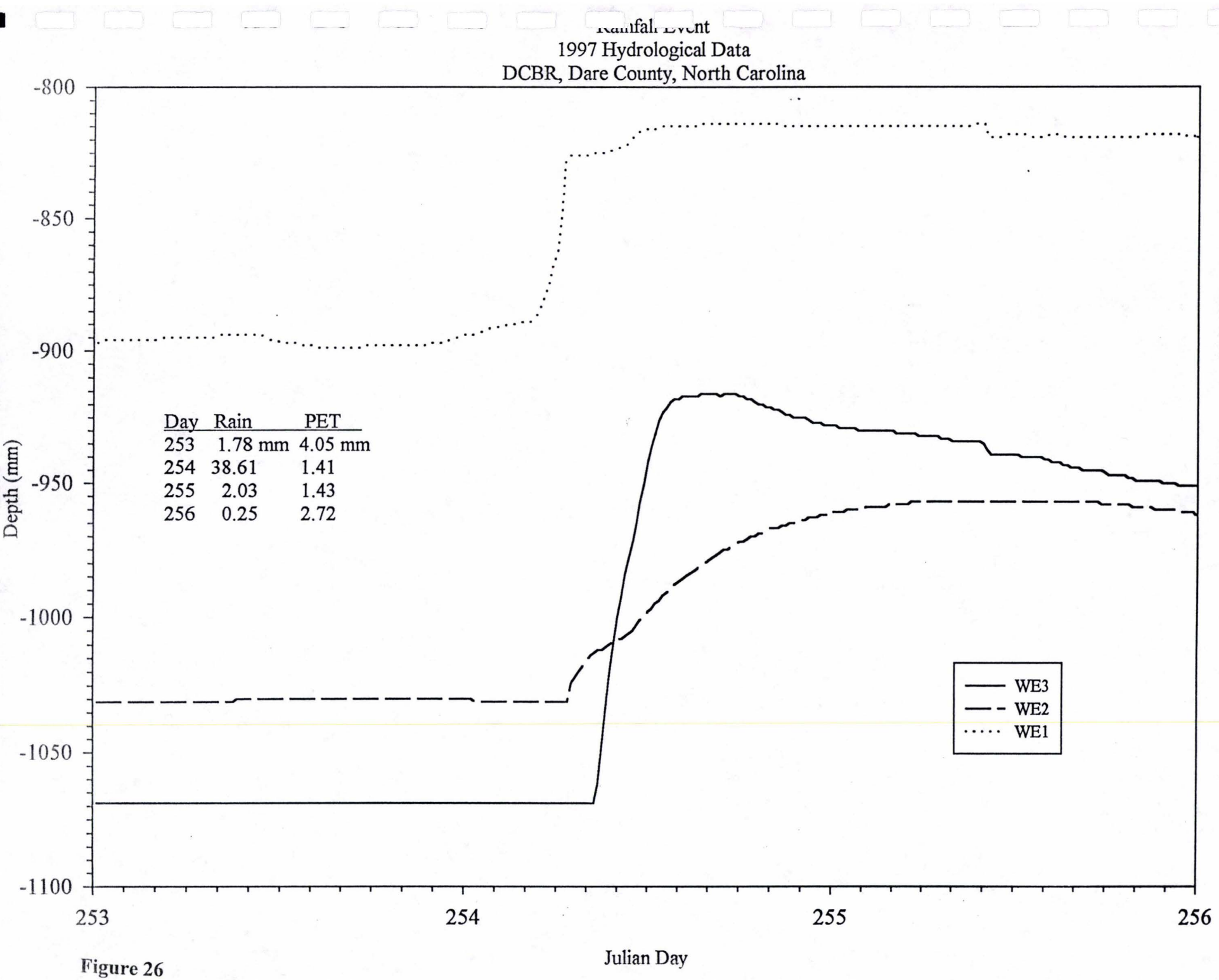
Rainfall Event
1997 Hydrological Data
DCBR, Dare County, North Carolina
-800
-850
-900
-950
-1000
-1050
-1100
Depth (mm)
Day Rain PET
253 1.78 mm 4.05 mm
254 38.61 1.41
255 2.03 1.43
256 0.25 2.72
WE3
WE2
WE1
253
254
255
256
Julian Day

Figure 26

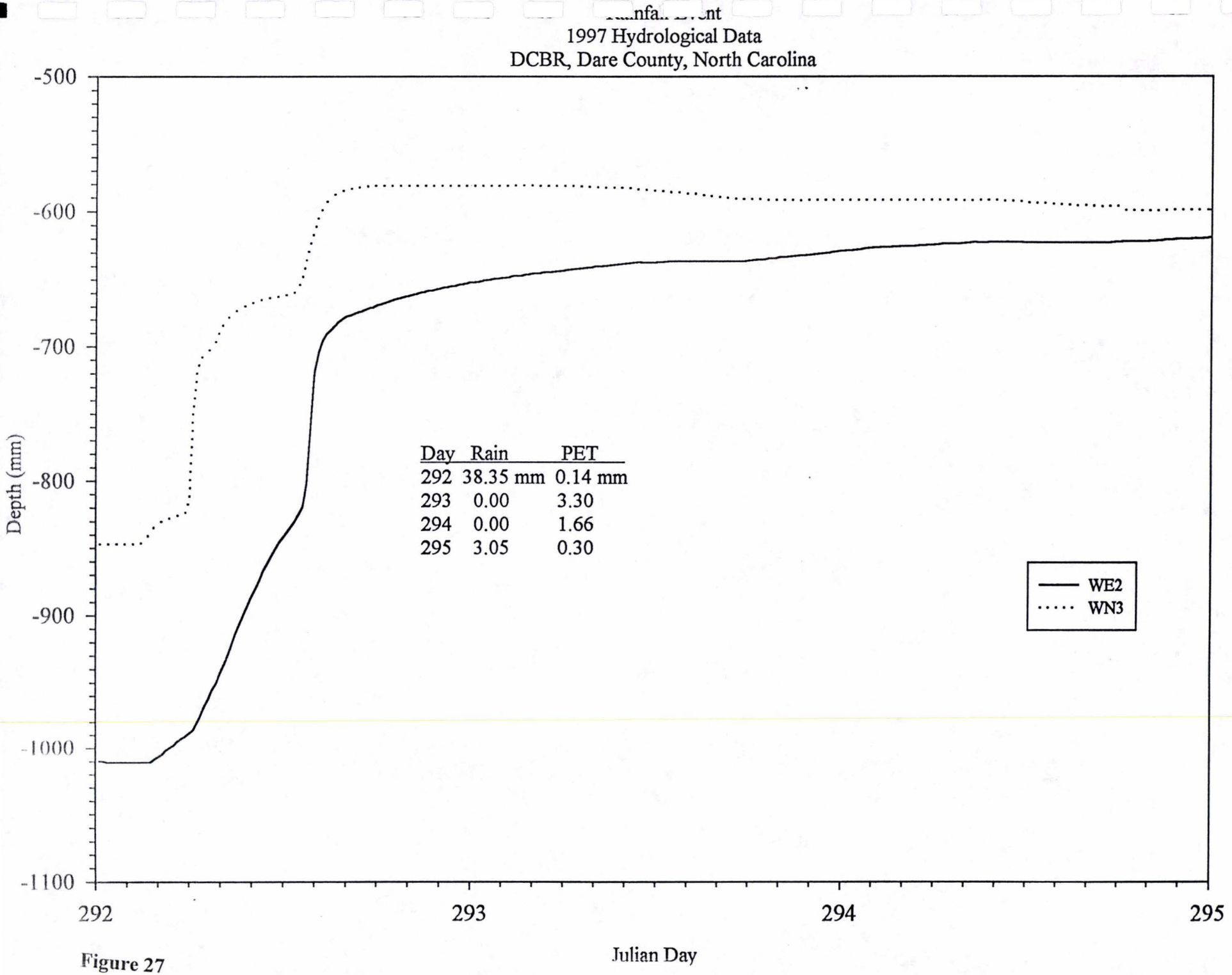
Rainfall Event
1997 Hydrological Data
DCBR, Dare County, North Carolina
-500
-600
-700
-800
-900
-1000
-1100
Depth (mm)
Day Rain PET
292 38.35 mm 0.14 mm
293 0.00 3.30
294 0.00 1.66
295 3.05 0.30
WE2
WN3
292
293
294
295
Julian Day

Figure 27

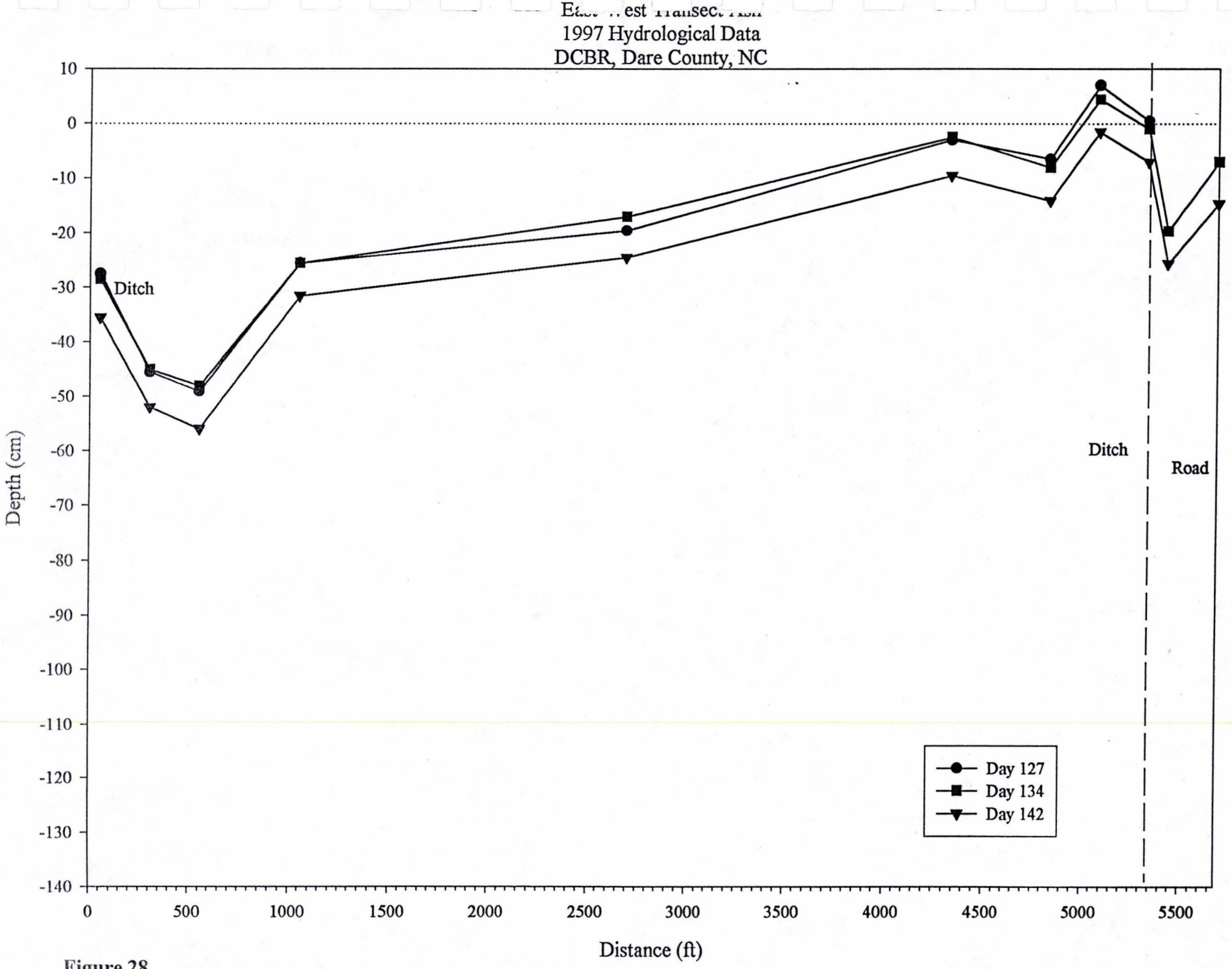
East West Transect
1997 Hydrological Data
DCBR, Dare County, NC
Depth (cm)
10
0
-10
-20
-30
-40
-50
-60
-70
-80
-90
-100
-110
-120
-130
-140
Ditch
Ditch
Road
Day 127
Day 134
Day 142
0
500
1000
1500
2000
2500
3000
3500
4000
4500
5000
5500
Distance (ft)

Figure 28

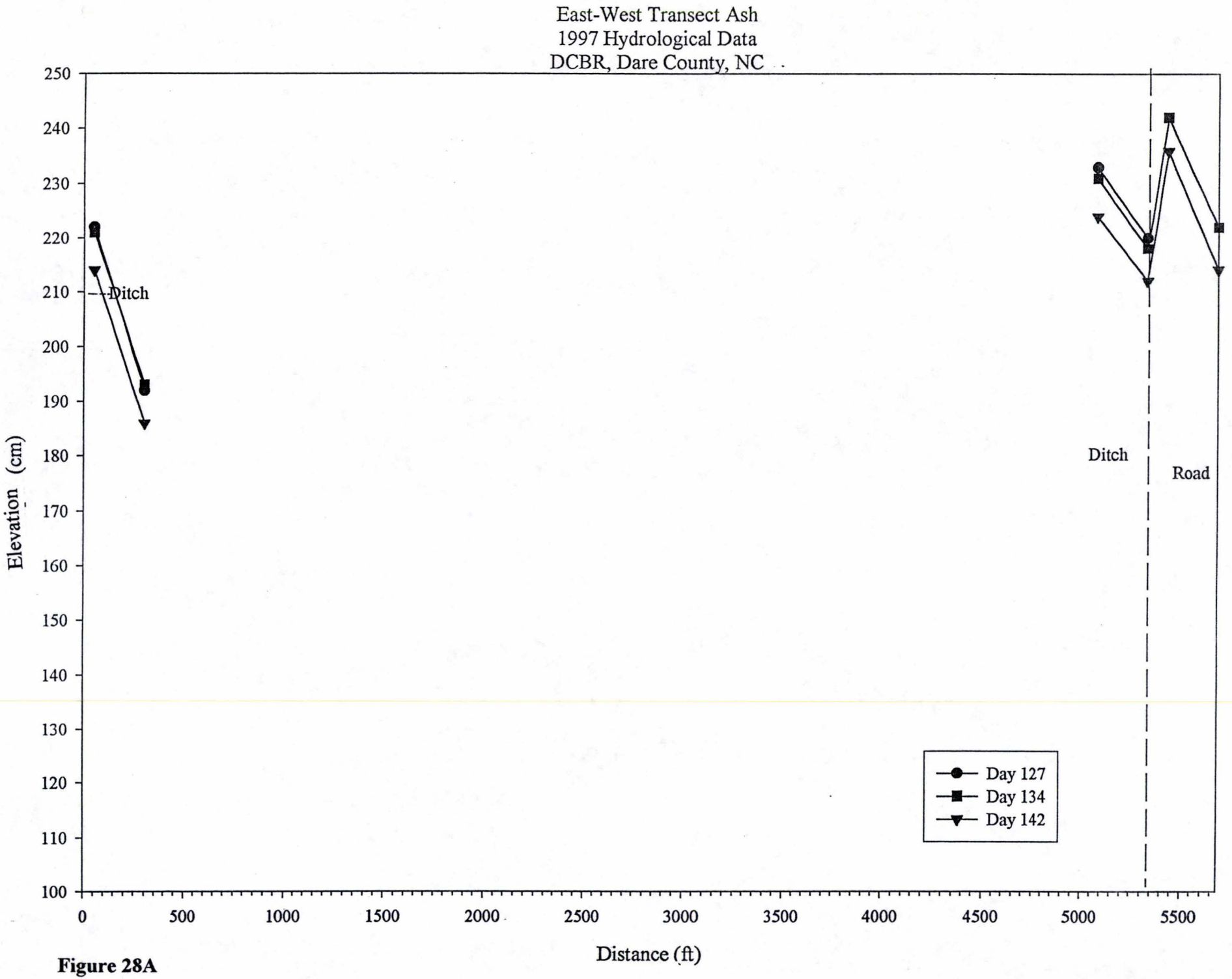
East-West Transect Ash
1997 Hydrological Data
DCBR, Dare County, NC
Elevation (cm)
250
240
230
220
210
200
190
180
170
160
150
140
130
120
110
100
Ditch
Ditch
Road
0
500
1000
1500
2000
2500
3000
3500
4000
4500
5000
5500
Distance (ft)
Day 127
Day 134
Day 142

Figure 28A

west in the fibric layer. However, for the dates shown in the Figures 28 and 28A, the water table is below the fibric layer everywhere along the transect except for a narrow strip adjacent to Beechland Road.

- The variation in water table depth and elevation among the more closely spaced wells is likely due to local relief and variation in ET. The extremely low gradients coupled with relatively low hydraulic conductivity in the sapric layer limits the water movement that would tend to equalize the elevations. As noted above, the rate of water table decline can vary significantly even when ET rates are the same. That is due to the microtopography and soil variation that causes variation in available water per unit of soil depth.
- The shallow water table depth at the western end of Ash block is due to the combined effects of a low area and the damming effect of Beechland Road. Note that the elevation at well AW1 is 21 cm lower than at AE1 (Table 4). The effect of a topographic high is seen in the water table depth and elevation in well BA1. The water table depth is deeper and the elevation is higher than in the adjacent wells.
- Variation in vegetation and resultant ET variation also contributes to variation in water table depth. A contribution to the "road effect" that is seen in all three transects may also be higher ET rates among the trees adjacent to the road. Those trees have larger crowns and are more exposed to radiation and wind than are the trees within the stand.

In Figures 29 and 29A are the Ash east-west transects for days 189, 197, and 206 (mid-July). The water table depth declined by about 50 cm from day 127 to day 206 and the gradient from east to west increased from about 30 cm on day 127 to about 40 cm. This again illustrates the phenomenon mentioned earlier. Under the same ET conditions, the water table declines more rapidly in soil zones with lower available water content. The water table is deeper into the sapric material on the east end of the block and the rate of decline is slightly higher. There is also somewhat less local variation in the water table depth among the closely spaced wells than was present in May.

In Figures 30 and 30A are the Ash east-west transects for days 329, 336, 345, and 355, illustrating the recharge cycle in late November and early December. The water table depth gradient across the block from east to west is again about 30 cm and there is a similar elevation gradient. It is interesting to note that the water table in wells BA1 and BA2 are now relatively higher compared to wells WW1 and WW2 than in the early and mid-summer. This indicates that the soil in the vicinity of those wells is recharging faster than on the east side of Beechland Road.

Waterfield East-West Transect

Three sample charts of the Waterfield east-west transects of water table depth and elevation are shown in Figures 31-33 and 31A-33A for the same dates as discussed above. Figures 31 and 31A show that the Waterfield east-west transect of water table depth and elevation is very similar in character to that in the Ash block (Figure 28) for mid-May. The water table depth was slightly nearer the surface throughout the Waterfield block, particularly being at or above the surface over a much larger portion of the western end of the block. However the general water table depth gradient from east to west was about the same, 30 cm. The transect of water table elevation across Waterfield block is somewhat different than for Ash block There is no gradient in water table elevation from east to west, but a significant downward gradient across Beechland

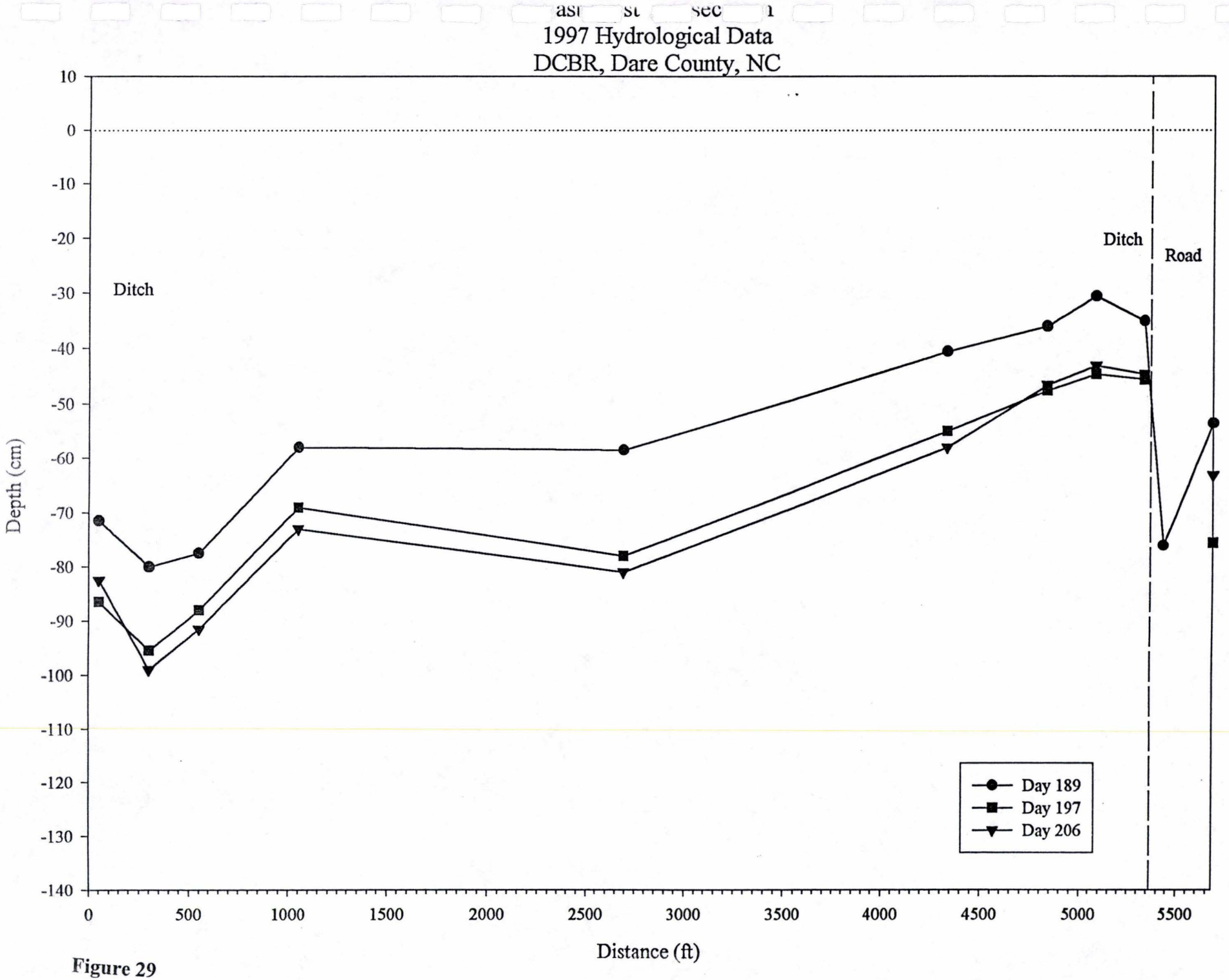
1997 Hydrological Data
DCBR, Dare County, NC
Ditch
Ditch
Road
Depth (cm)
Distance (ft)
Day 189
Day 197
Day 206
10
0
-10
-20
-30
-40
-50
-60
-70
-80
-90
-100
-110
-120
-130
-140
0
500
1000
1500
2000
2500
3000
3500
4000
4500
5000
5500

Figure 29

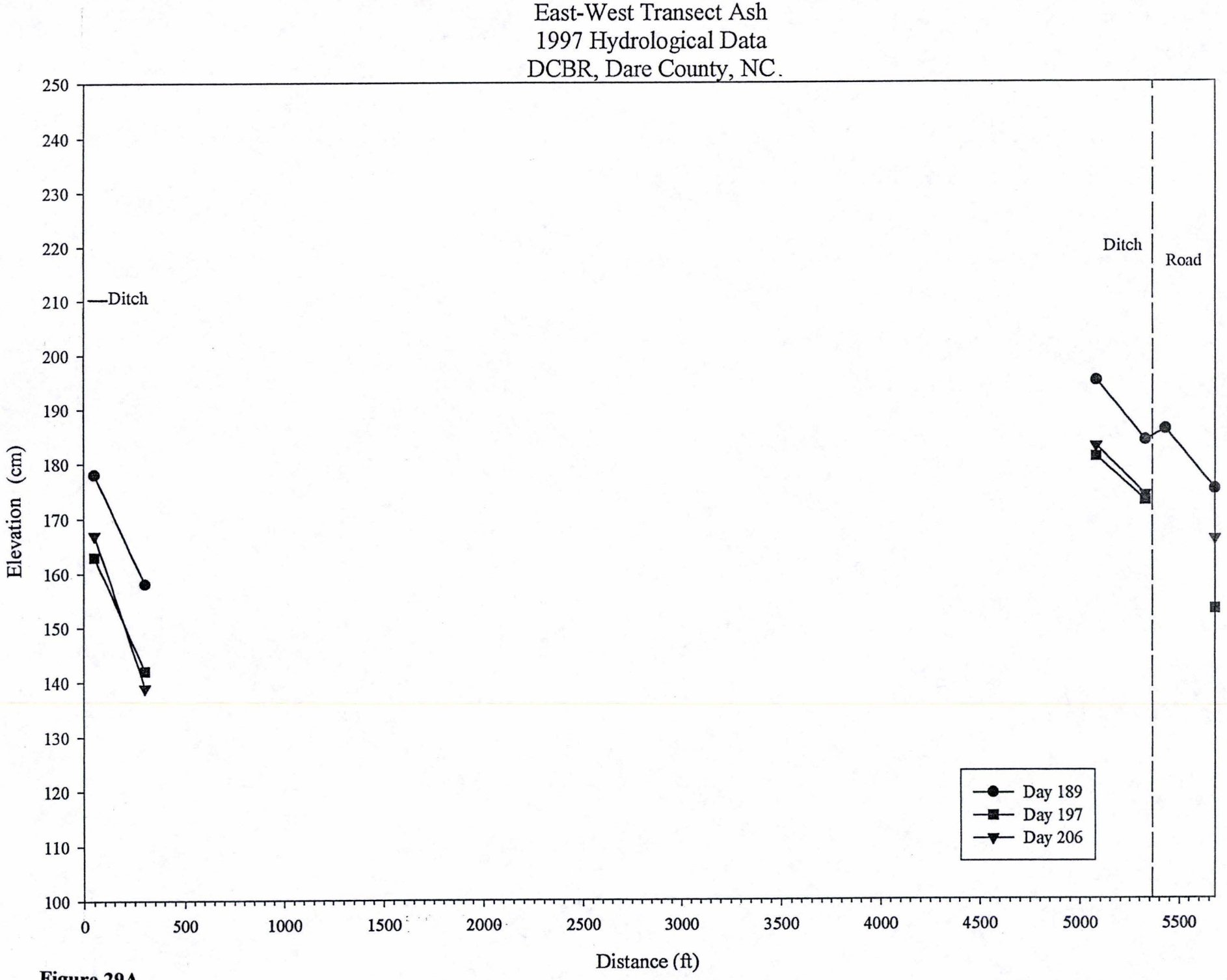
East-West Transect Ash
1997 Hydrological Data
DCBR, Dare County, NC.
Elevation (cm)
Distance (ft)
Ditch
Ditch
Road
Day 189
Day 197
Day 206
250
240
230
220
210
200
190
180
170
160
150
140
130
120
110
100
0
500
1000
1500
2000
2500
3000
3500
4000
4500
5000
5500

Figure 29A

East-West Transect Ash
1997 Hydrological Data
DCBR, Dare County, North Carolina

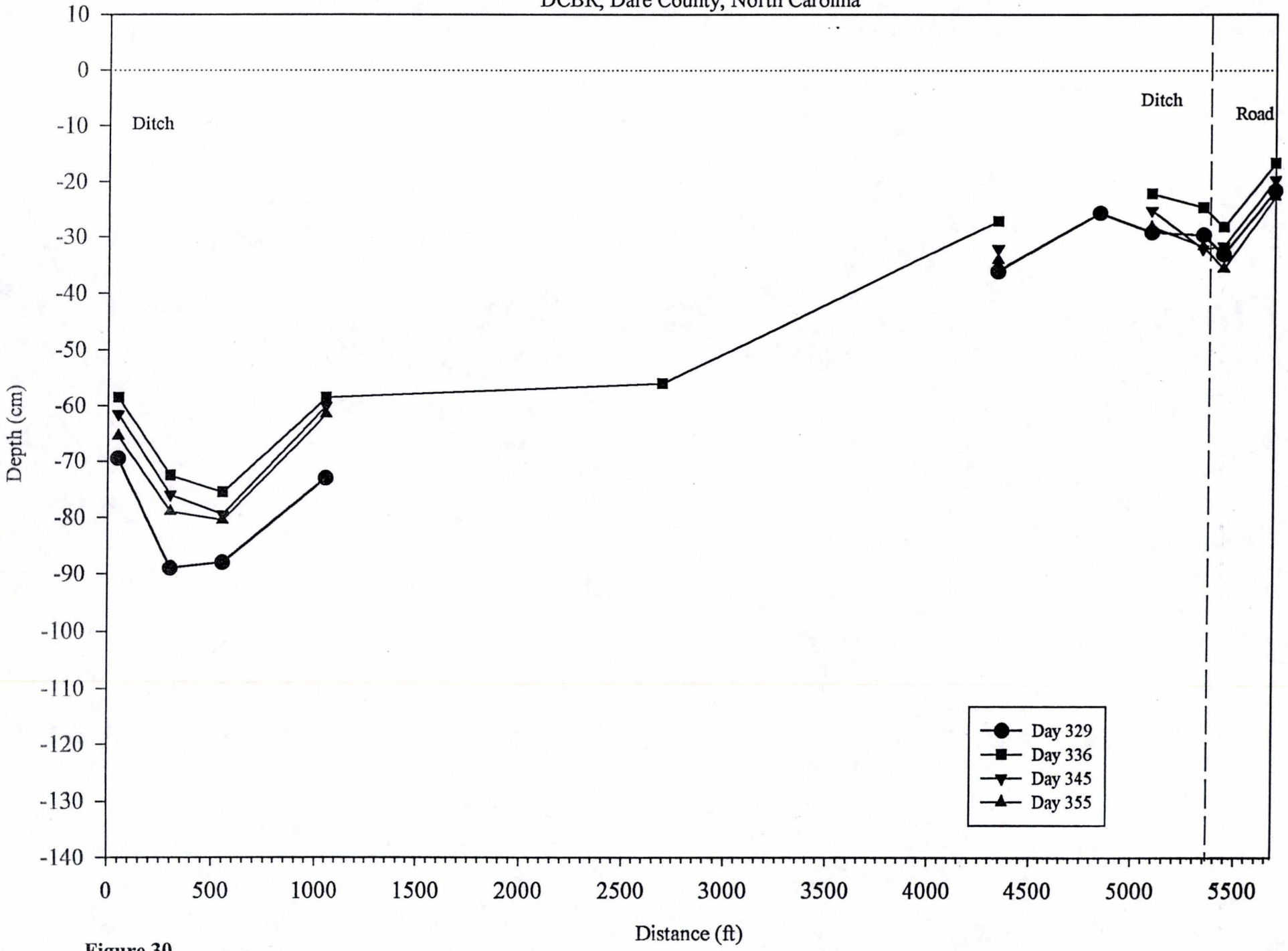

Figure 30

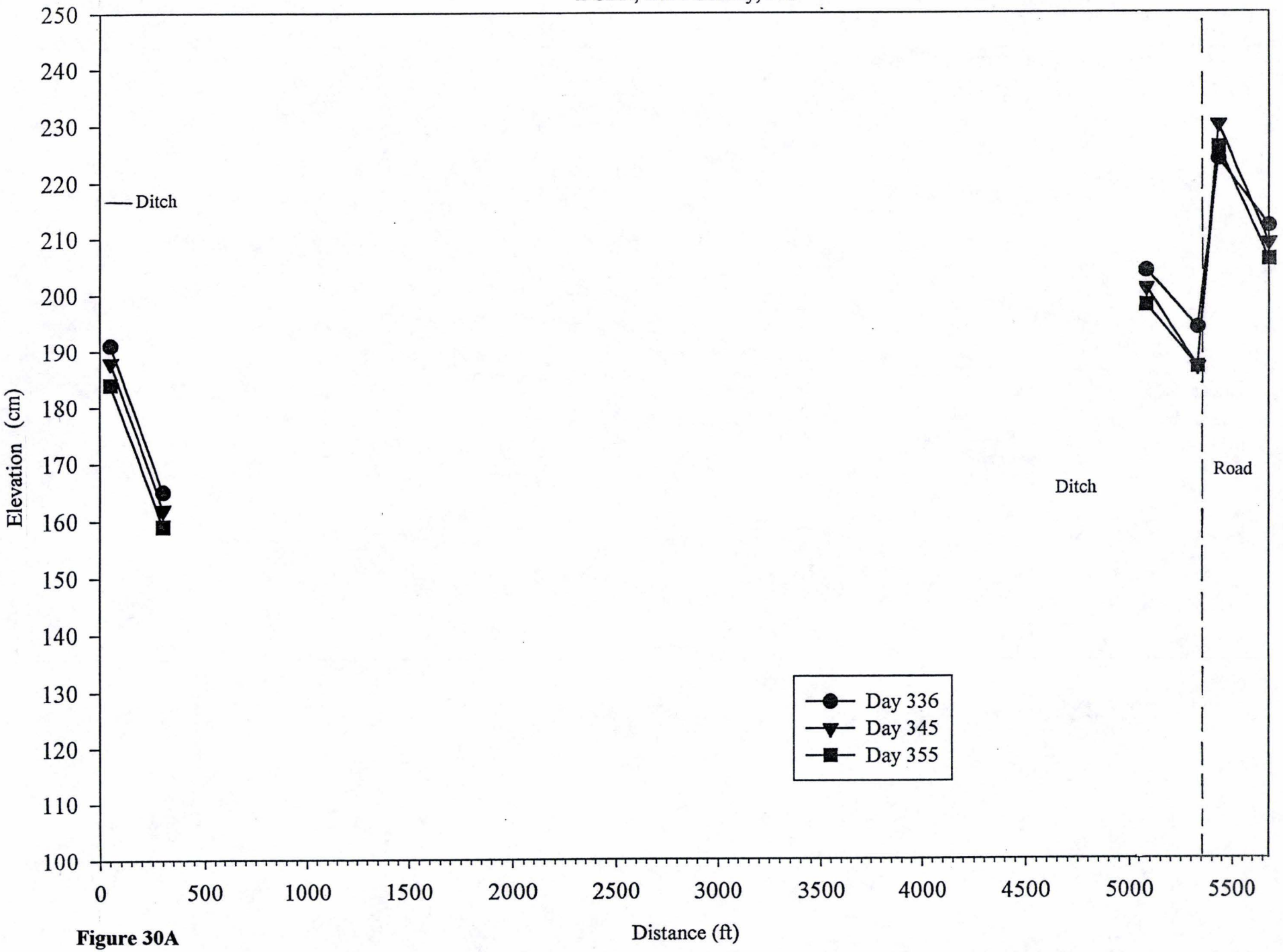
East-West Transect Ash
1997 Hydrological Data
DCBR, Dare County, NC
Elevation (cm)
250
240
230
220
210
200
190
180
170
160
150
140
130
120
110
100
Ditch
Ditch
Road
Day 336
Day 345
Day 355
0
500
1000
1500
2000
2500
3000
3500
4000
4500
5000
5500
Distance (ft)

Figure 30A

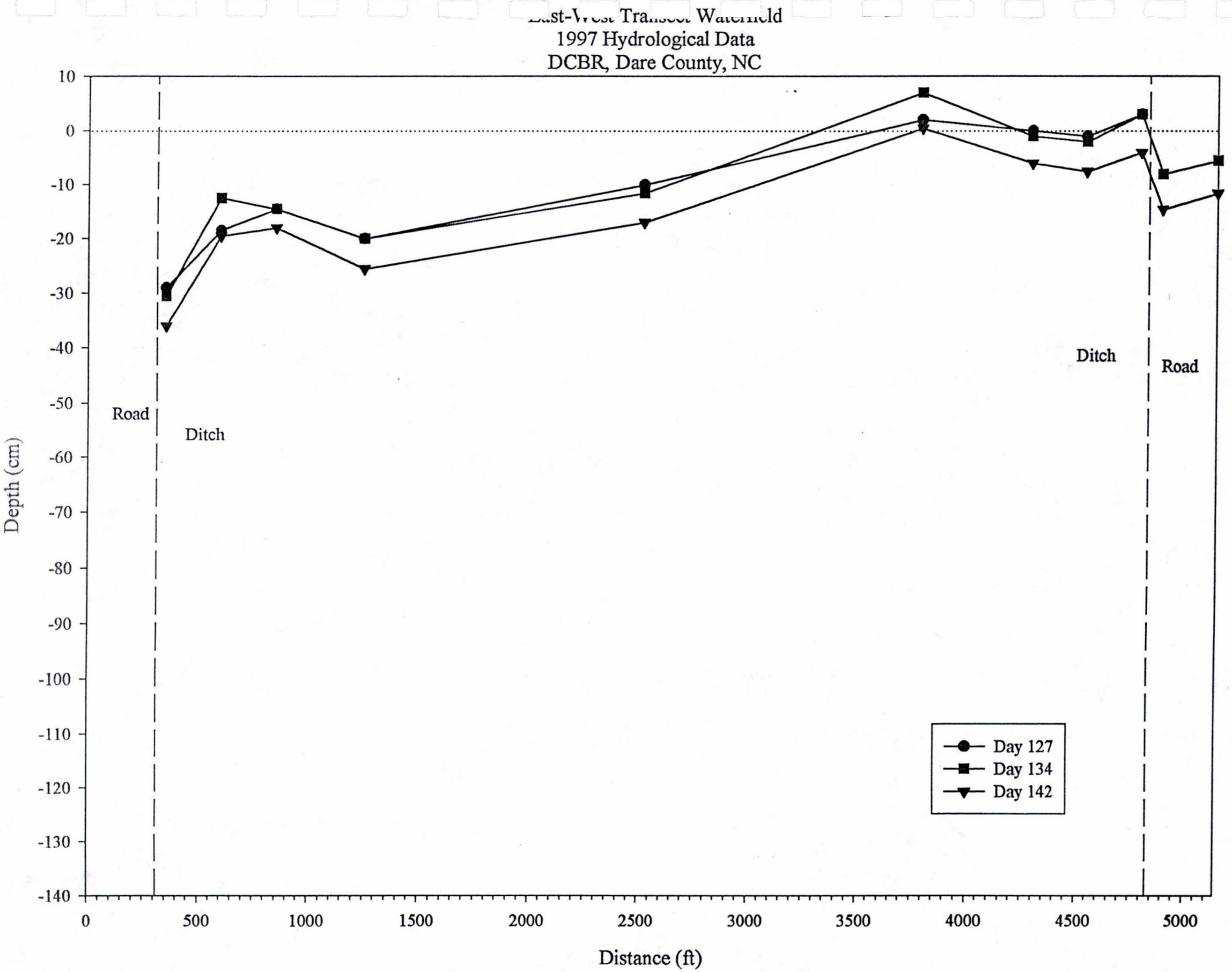
East-West Transect Waterfield
1997 Hydrological Data
DCBR, Dare County, NC
Depth (cm)
10
0
-10
-20
-30
-40
-50
-60
-70
-80
-90
-100
-110
-120
-130
-140
Road
Ditch
Ditch
Road
0
500
1000
1500
2000
2500
3000
3500
4000
4500
5000
Distance (ft)
Day 127
Day 134
Day 142

Figure 31

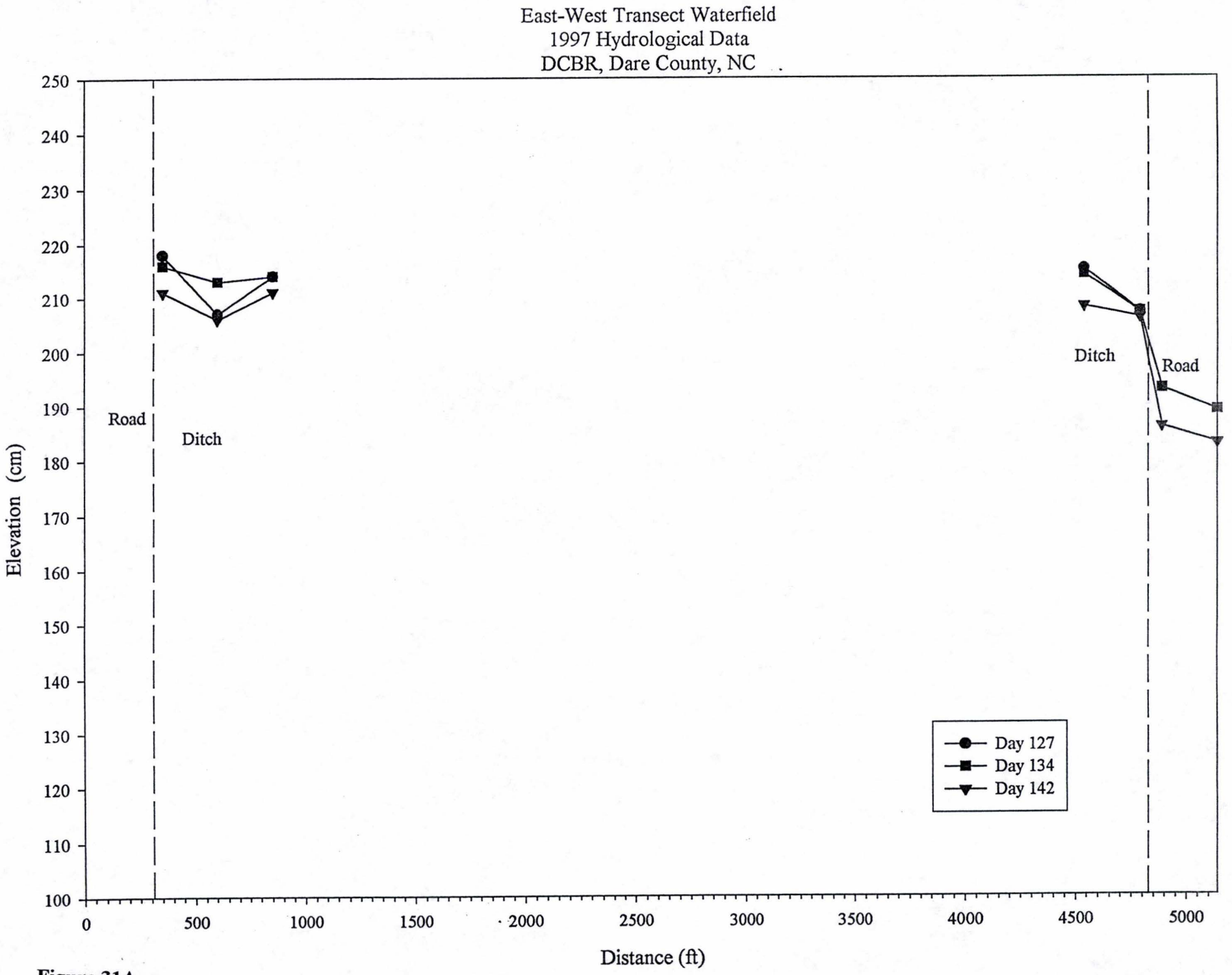
East-West Transect Waterfield
1997 Hydrological Data
DCBR, Dare County, NC
Elevation (cm)
250
240
230
220
210
200
190
180
170
160
150
140
130
120
110
100
Road
Ditch
Ditch
Road
Day 127
Day 134
Day 142
0
500
1000
1500
2000
2500
3000
3500
4000
4500
5000
Distance (ft)

Figure 31A

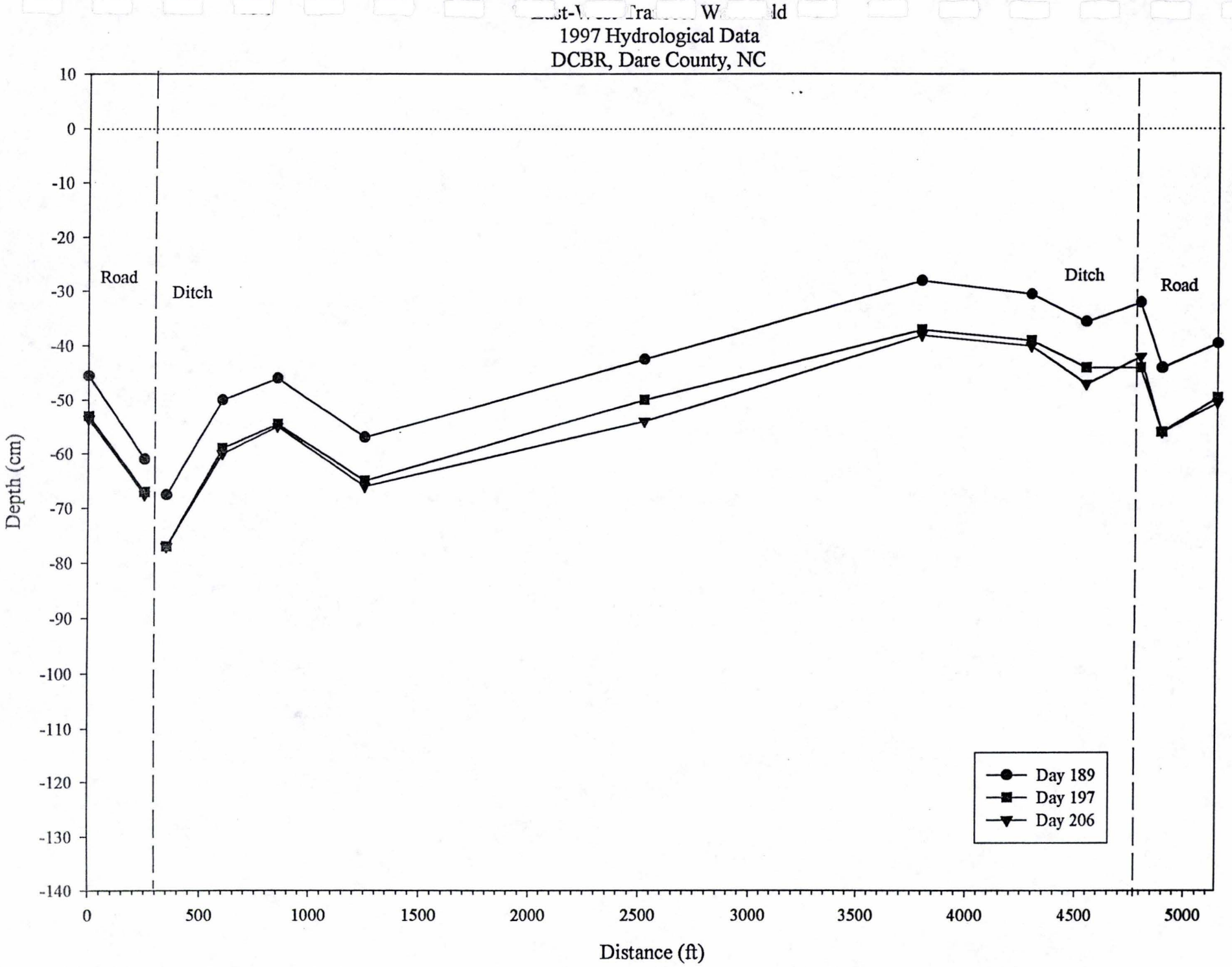
1997 Hydrological Data
DCBR, Dare County, NC
Road
Ditch
Ditch
Road
Depth (cm)
Distance (ft)
Day 189
Day 197
Day 206
10
0
-10
-20
-30
-40
-50
-60
-70
-80
-90
-100
-110
-120
-130
-140
0
500
1000
1500
2000
2500
3000
3500
4000
4500
5000

Figure 32

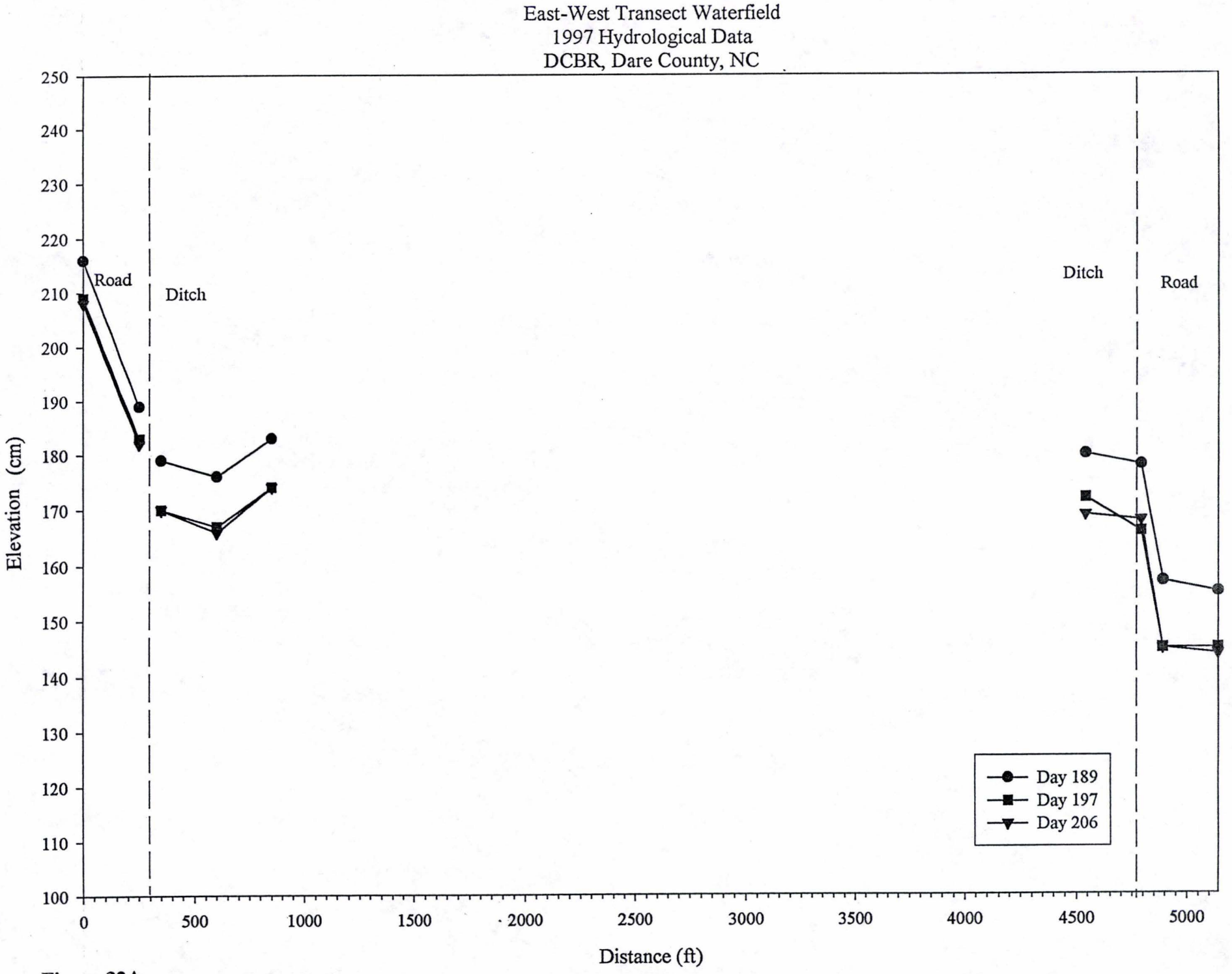
East-West Transect Waterfield
1997 Hydrological Data
DCBR, Dare County, NC
Elevation (cm)
250
240
230
220
210
200
190
180
170
160
150
140
130
120
110
100
Road
Ditch
Ditch
Road
0
500
1000
1500
2000
2500
3000
3500
4000
4500
5000
Distance (ft)
Day 189
Day 197
Day 206

Figure 32A

1997 Hydrological Data
DCBR, Dare County, North Carolina

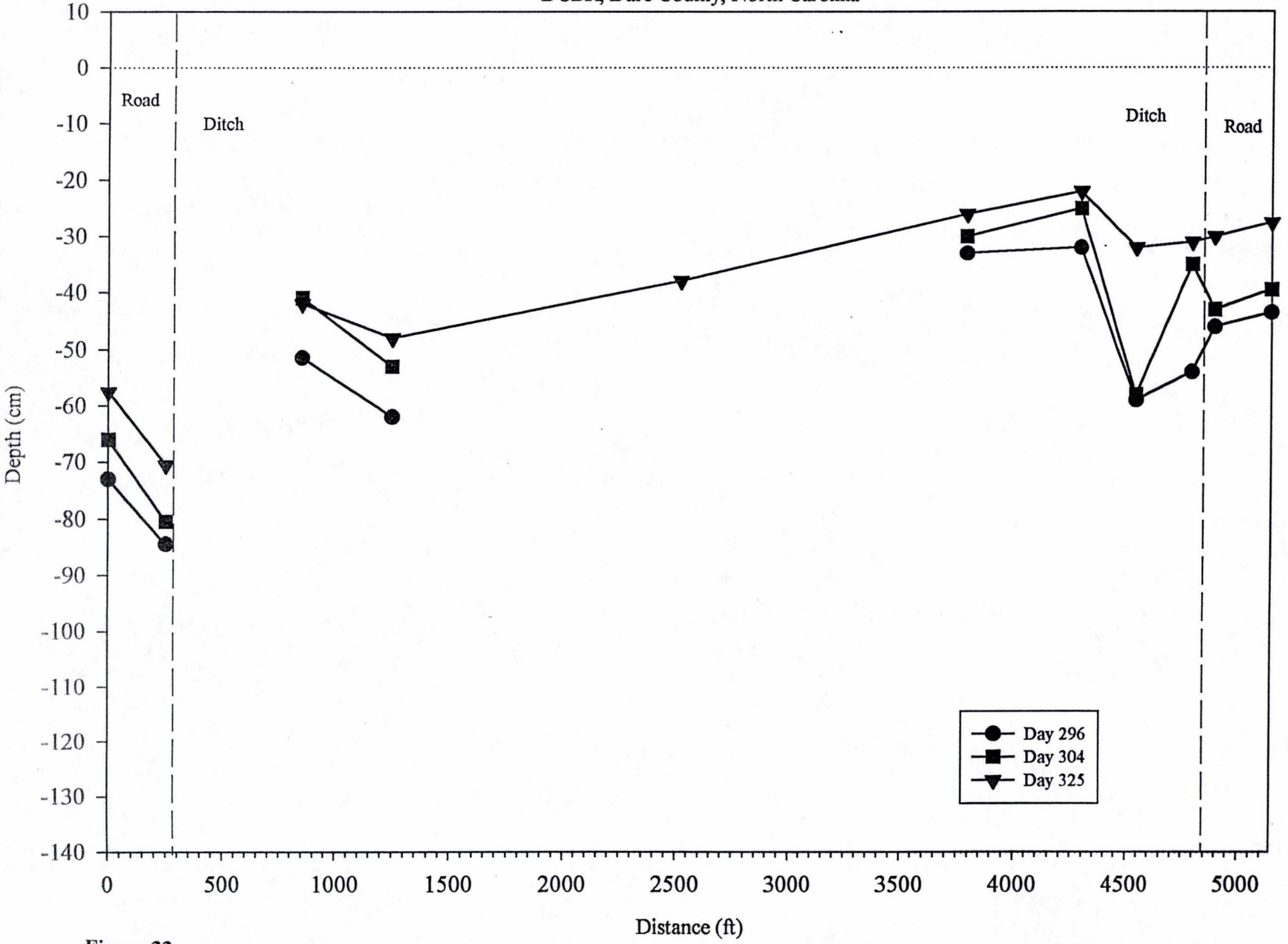

Figure 33

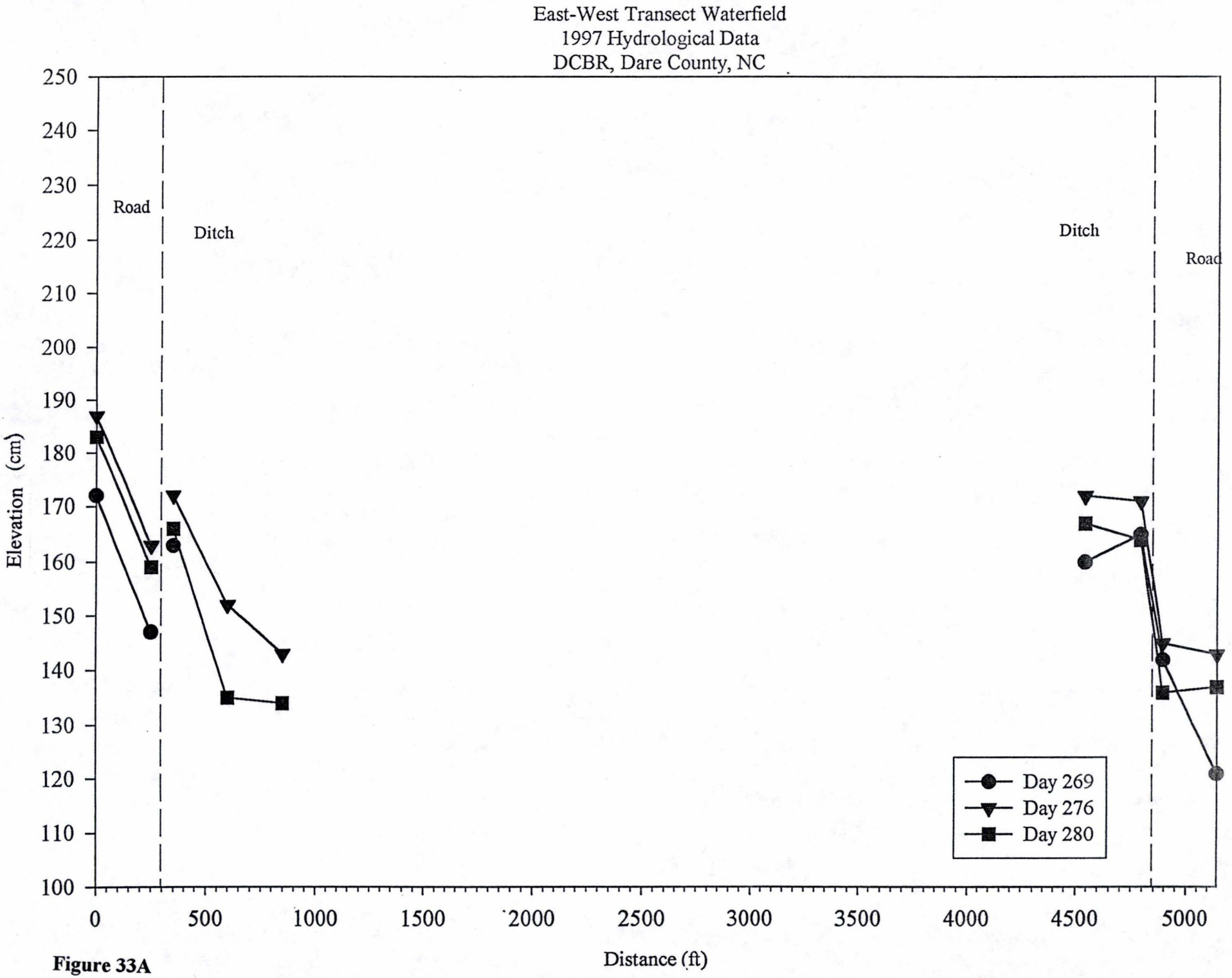
East-West Transect Waterfield
1997 Hydrological Data
DCBR, Dare County, NC
Road
Ditch
Ditch
Road
Elevation (cm)
250
240
230
220
210
200
190
180
170
160
150
140
130
120
110
100
0
500
1000
1500
2000
2500
3000
3500
4000
4500
5000
Distance (ft)
Day 269
Day 276
Day 280

Figure 33A

Road. The variation in water table depth among the closely spaced wells differed from that in Ash block, again indicating that random local relief is probably the major factor in that variation.

In Figures 32 and 32A are the Waterfield east-west water table depth and elevation transects for mid-July, again showing a pattern of water table depth variation similar to that in Ash block. The water table elevation had declined about 40 cm since May and the gradient across Beechland Road had increased, again indicative of the damming effect of the road. Wells FW1 and FW2 were installed prior to day 189. The difference in water table depth between those two wells is likely due to local relief. The greater depth of the water table in FW1 may also be due in part to greater ET rates among the road side trees. The elevation gradient between FW wells and the WE wells indicates that Faircloth Road may also be serving to block subsurface flow along a natural gradient to the west.

In Figures 33 and 33A are the Waterfield east-west water table depth and elevation transects for late October to mid-November. As with the Ash transect, the water table in the vicinity of the wells on the western side of Beechland Road seems to be recharging faster than the wells on the eastern side of the road.

Waterfield-Ash North-South Transect

Three sample charts of the Waterfield-Ash north-south water table depth and elevation transect are shown in Figures 34-36 and 34A-36B for the same dates as discussed above. The chart of Figure 34 shows the water table transect from well WN1 on the left edge to well AS1 on the right edge. The small surface gradient (decreasing elevation) across Ash and Waterfield blocks from south to north is reflected in the gradient of increasing water table depth from north to south across both blocks. There also appears to be a very small gradient of decreasing water table elevation from south to north across the two blocks. It is difficult to separate the effects of the general surface gradient from that of local relief on variation of water table depth. However, the north to south water table depth gradient across Waterfield block is about 30 cm and across Ash block is about 20 cm. The difference in water table depth between well WS1 adjacent to the Waterfield Road ditch (about 25 cm depth on day 142) and AN1 on the opposite side of the road (about 50 cm depth on day 142) is somewhat puzzling. That difference may simply be due to local relief; wells AN1 and AN2 are at somewhat higher elevations than wells WS1 and WS2. However, the same pattern of variation occurs in water table elevation.

Figures 35 and 35A show the Waterfield-Ash north-south water table depth and elevation transects for mid-July. At that time the difference in water table depth between wells WS1 and AN1 has increased, a difference of about 70 cm on day 206. That may reflect a combination of recharge from the ditch into the soil in the vicinity of well WS1 and greater ET rates for the trees adjacent to the road on the north side of Ash block where the ditch recharge is not available. The fact that the water table depth in well AS1 adjacent to the Ash road ditch has not decreased as rapidly as that at wells to the north also indicates that ditch recharge occurred.

Figures 36 and 36A and B show the Waterfield-Ash north-south water table depth and elevation transects for the late November to mid-December period when the water table was recharging. The pattern of water table depth variation across the two blocks is similar to that during water

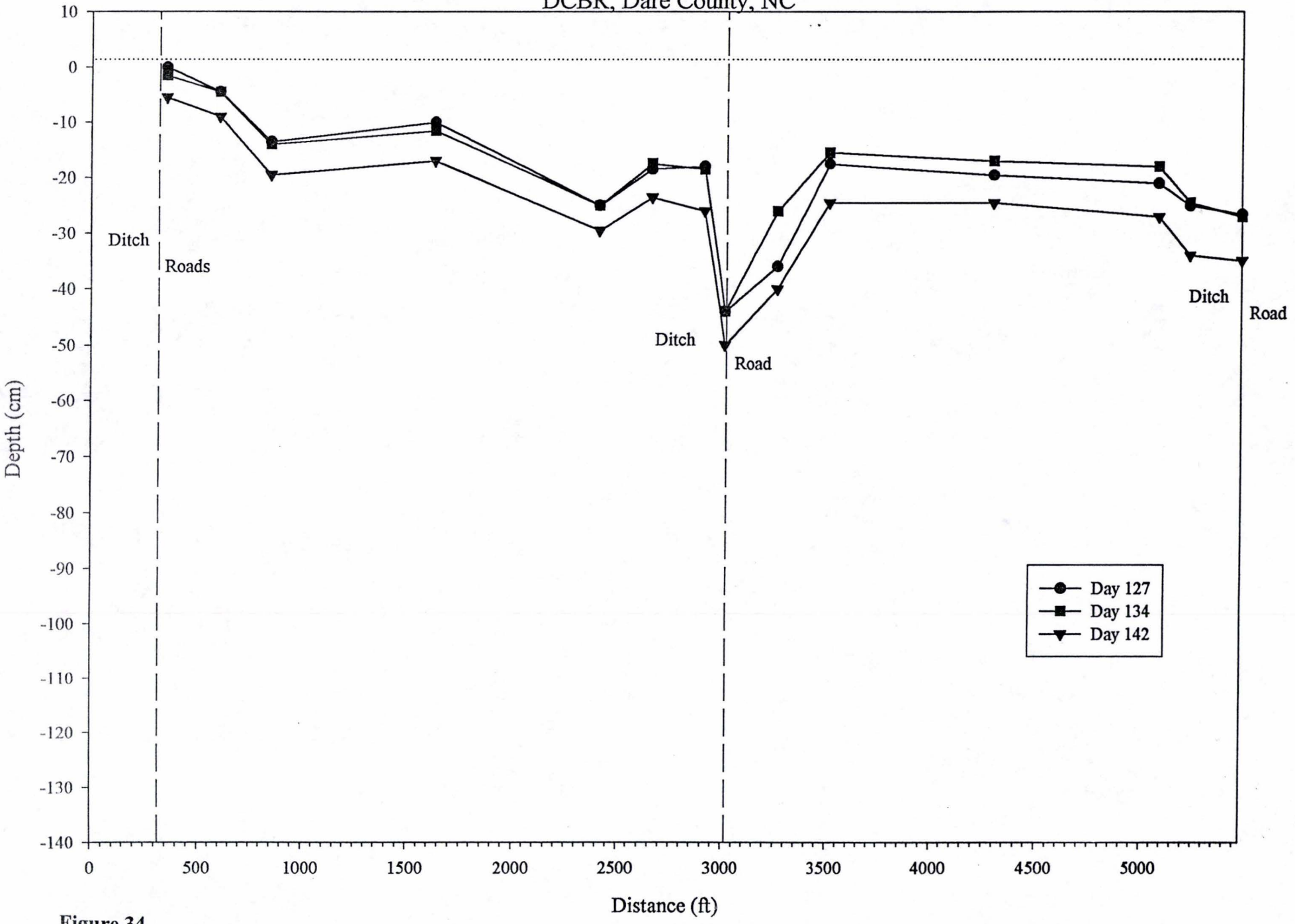
1997 Hydrological Data
DCBR, Dare County, NC
Depth (cm)
10
0
-10
-20
-30
-40
-50
-60
-70
-80
-90
-100
-110
-120
-130
-140
0
500
1000
1500
2000
2500
3000
3500
4000
4500
5000
Distance (ft)
Ditch
Roads
Ditch
Road
Ditch
Road
Day 127
Day 134
Day 142

Figure 34

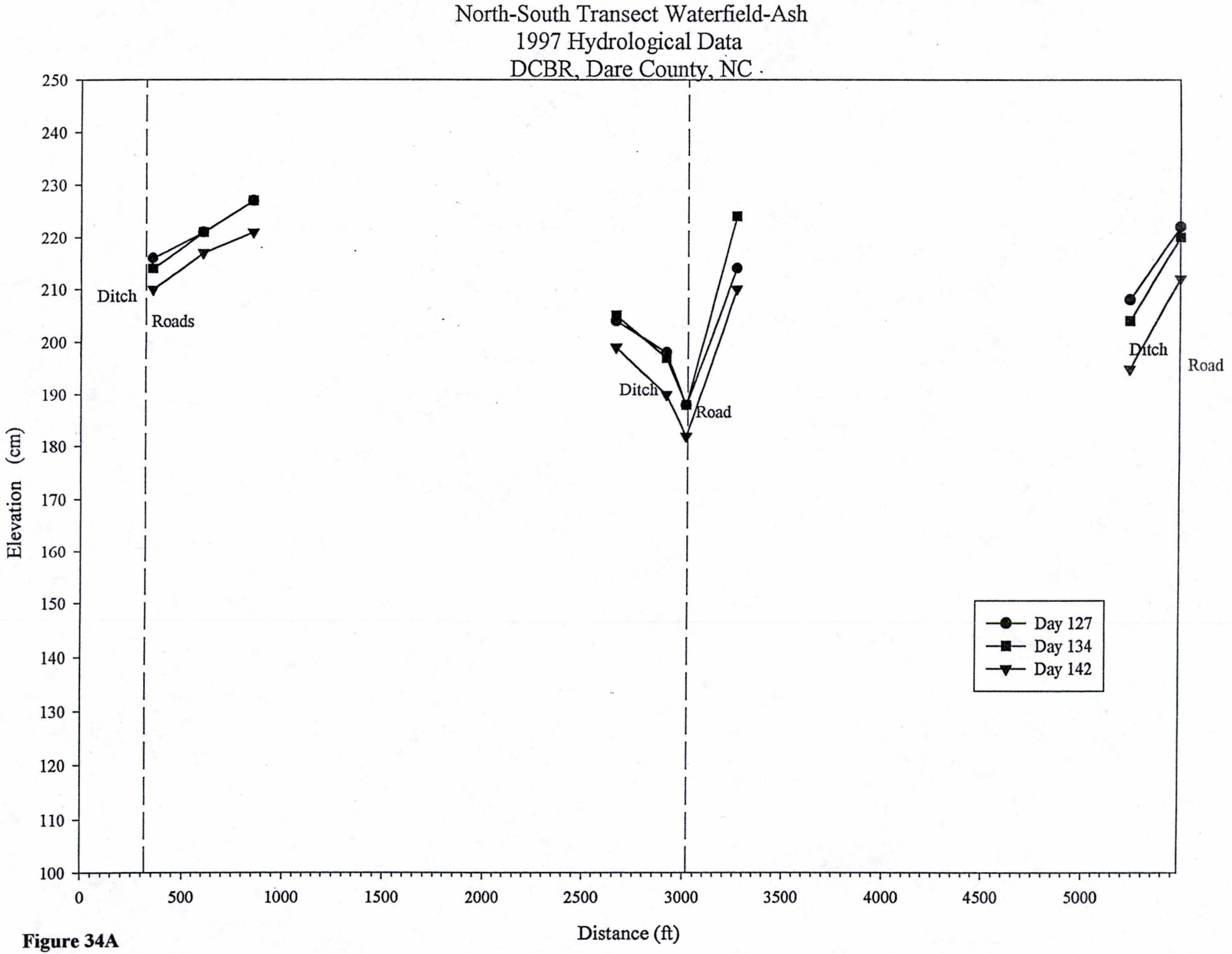
North-South Transect Waterfield-Ash
1997 Hydrological Data
DCBR, Dare County, NC
Elevation (cm)
250
240
230
220
210
200
190
180
170
160
150
140
130
120
110
100
Ditch
Roads
Ditch
Road
Ditch
Road
Day 127
Day 134
Day 142
0
500
1000
1500
2000
2500
3000
3500
4000
4500
5000
Distance (ft)

Figure 34A

1997 Hydrological Data
DCBR, Dare County, NC

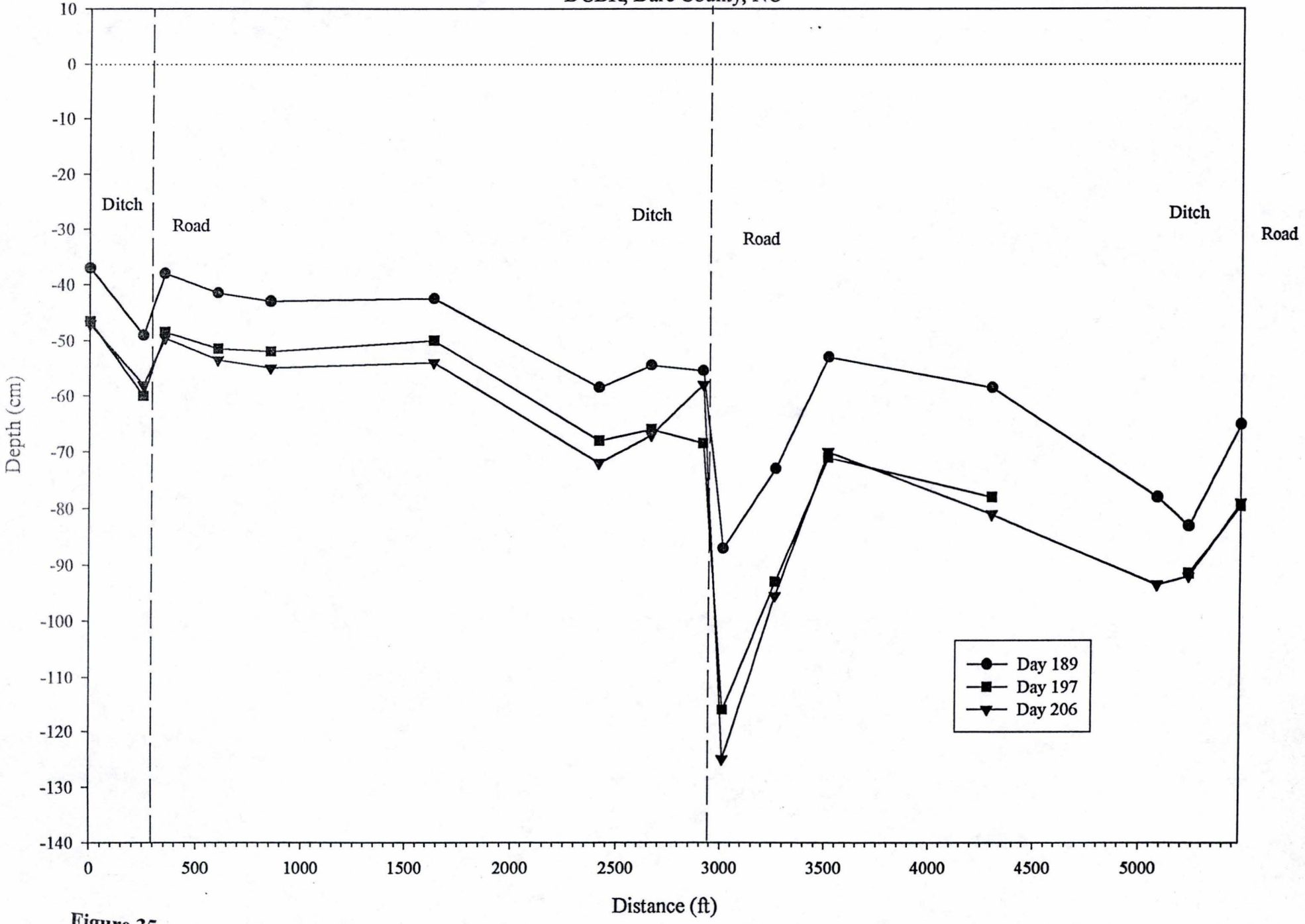

Figure 35

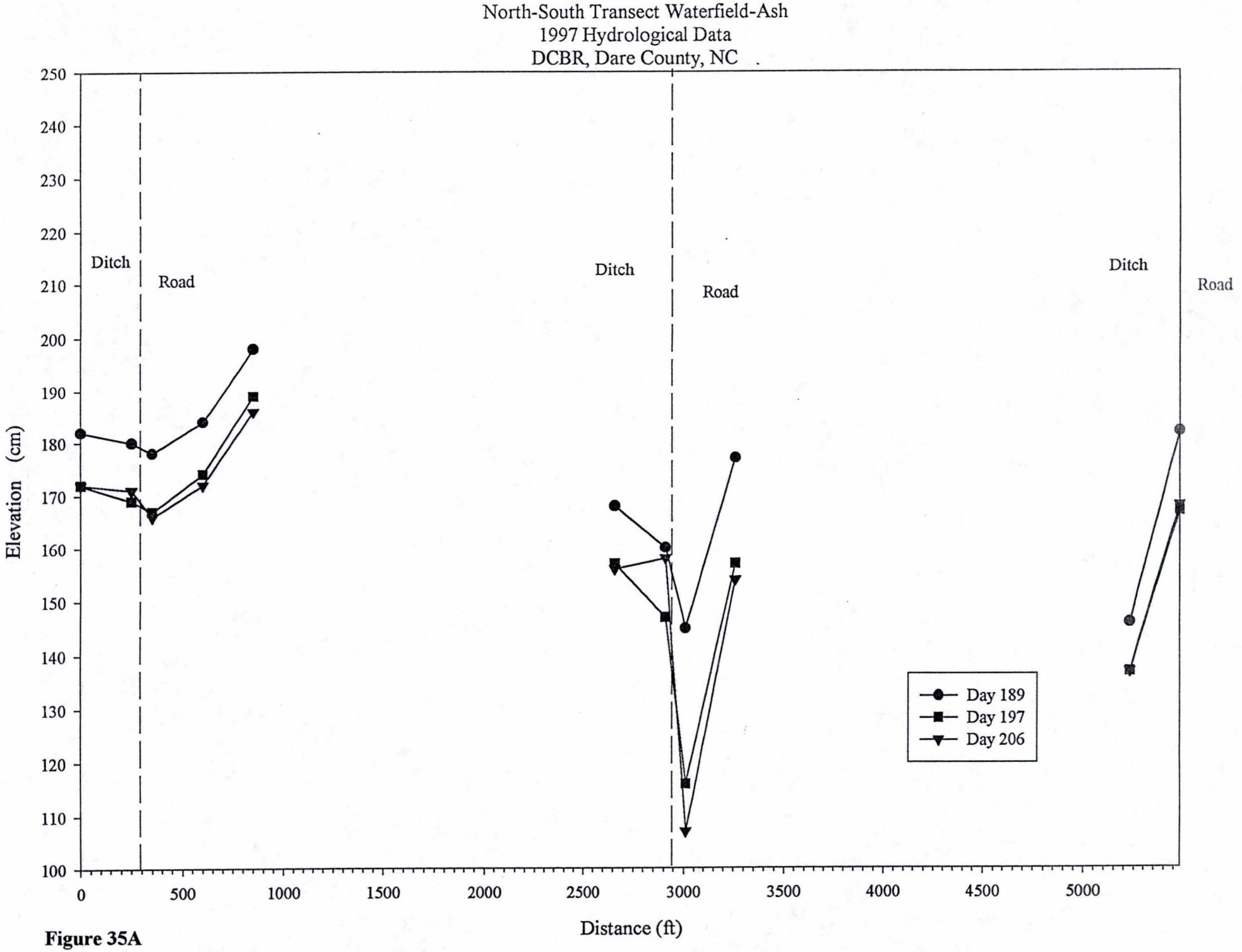
North-South Transect Waterfield-Ash
1997 Hydrological Data
DCBR, Dare County, NC
Ditch
Road
Ditch
Road
Ditch
Road
Elevation (cm)
Distance (ft)
Day 189
Day 197
Day 206
250
240
230
220
210
200
190
180
170
160
150
140
130
120
110
100
0
500
1000
1500
2000
2500
3000
3500
4000
4500
5000

Figure 35A

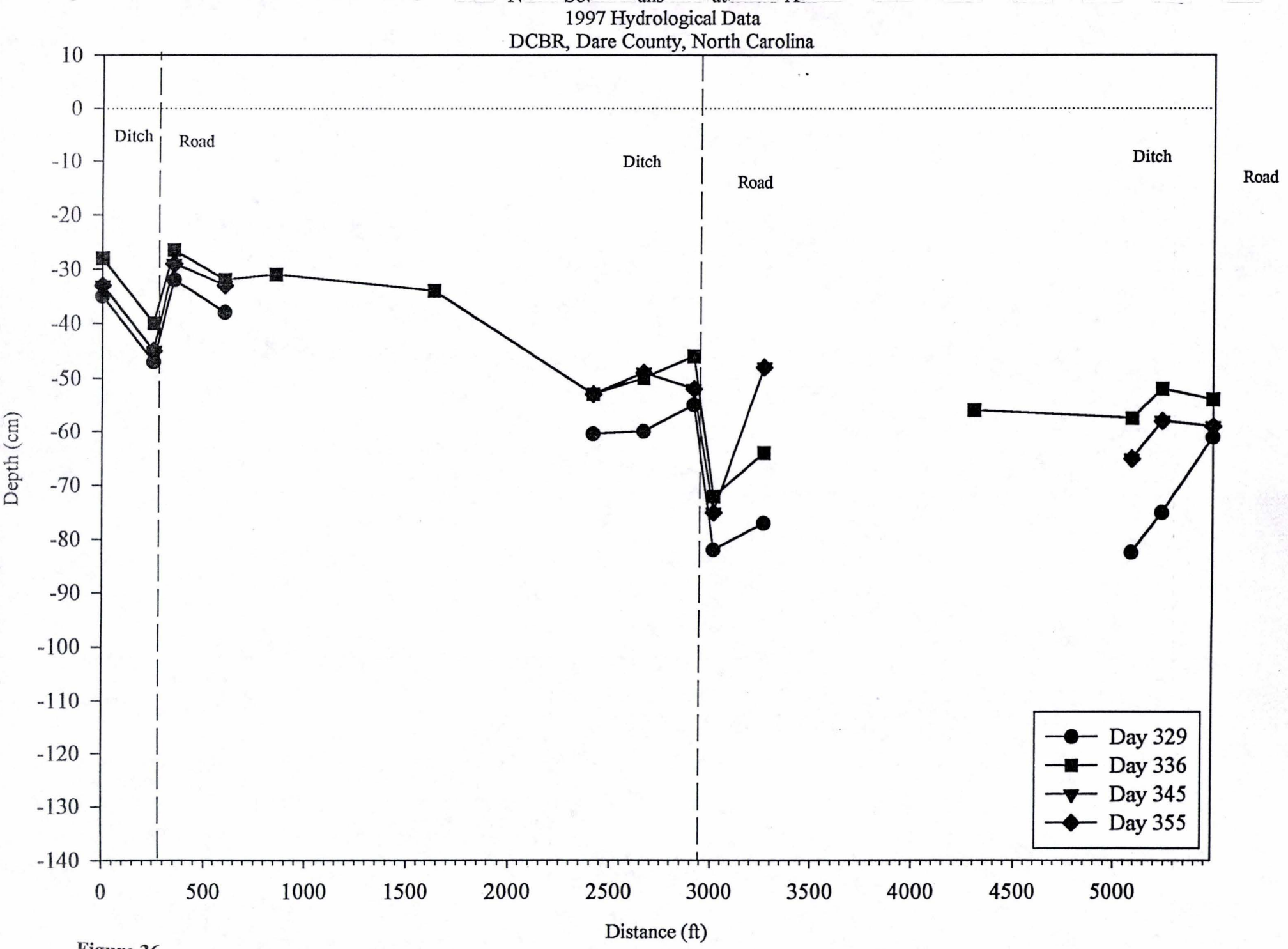
1997 Hydrological Data
DCBR, Dare County, North Carolina
Ditch
Road
Ditch
Road
Ditch
Road
Depth (cm)
Distance (ft)
Day 329
Day 336
Day 345
Day 355

Figure 36

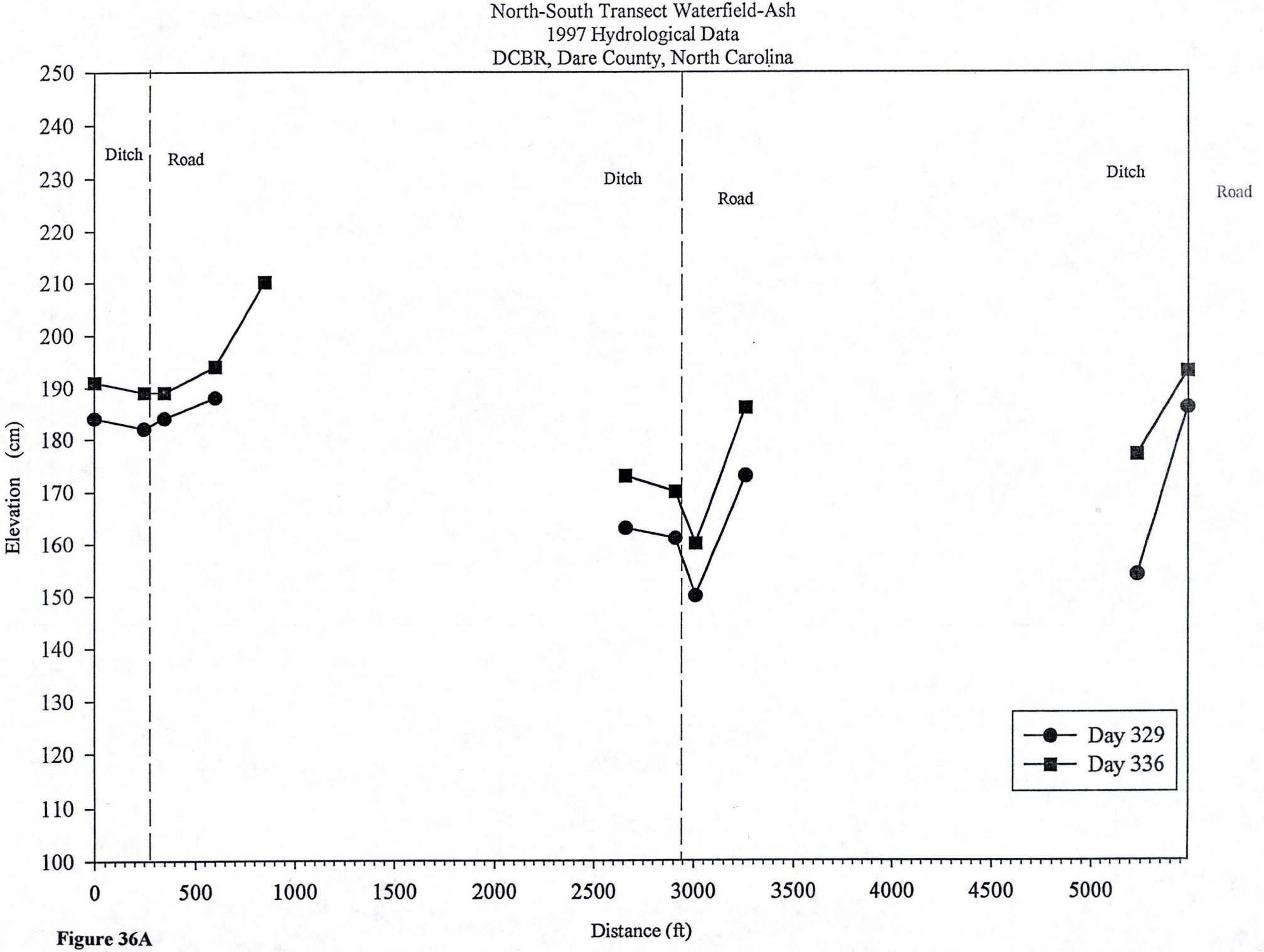
North-South Transect Waterfield-Ash
1997 Hydrological Data
DCBR, Dare County, North Carolina
Ditch
Road
Ditch
Road
Ditch
Road
Elevation (cm)
250
240
230
220
210
200
190
180
170
160
150
140
130
120
110
100
0
500
1000
1500
2000
2500
3000
3500
4000
4500
5000
Distance (ft)
Day 329
Day 336

Figure 36A

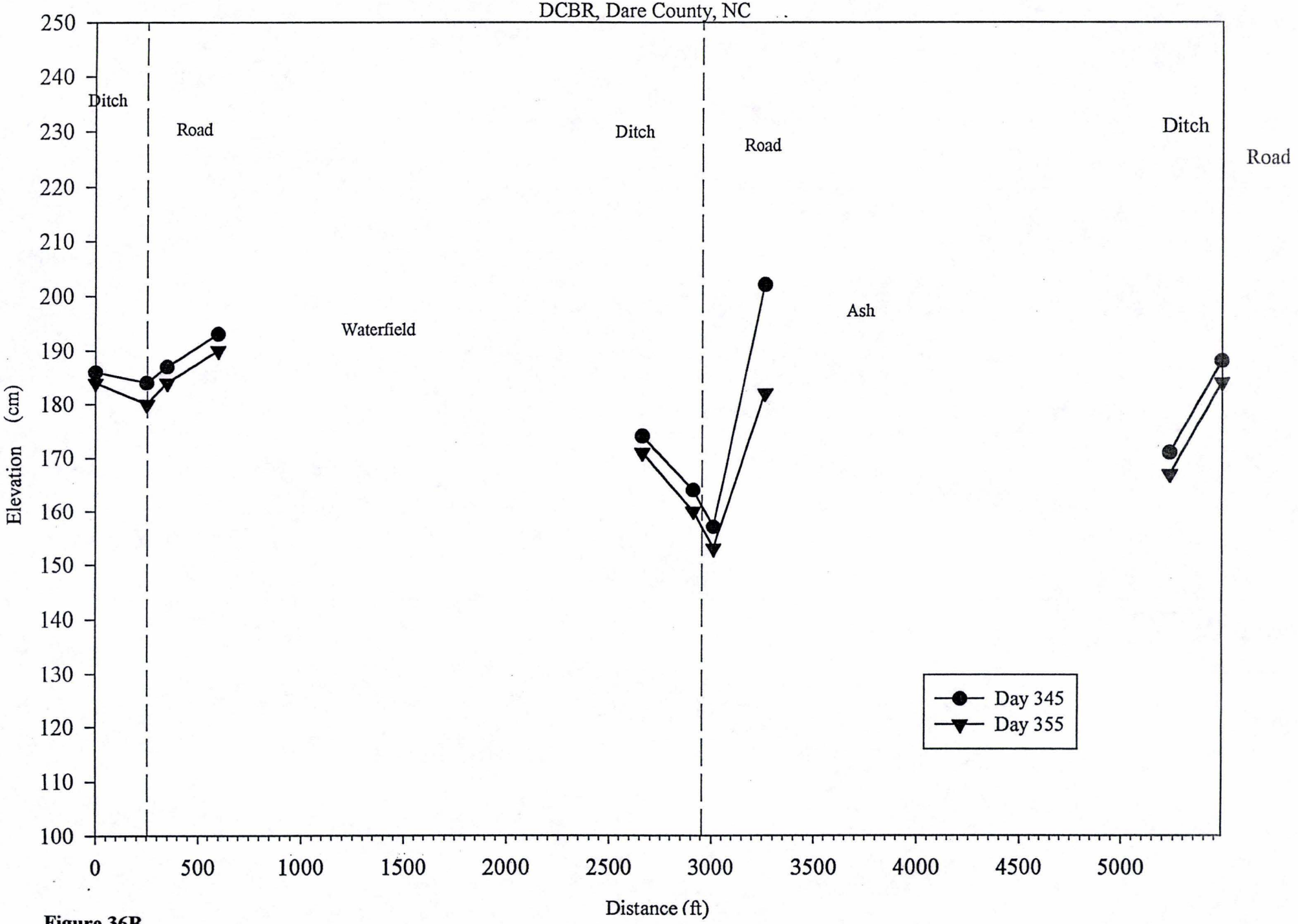
North-South Transect Waterfield-Ash
1997 Hydrological Data
DCBR, Dare County, NC
Ditch
Road
Waterfield
Ditch
Road
Ash
Ditch
Road
Elevation (cm)
250
240
230
220
210
200
190
180
170
160
150
140
130
120
110
100
0
500
1000
1500
2000
2500
3000
3500
4000
4500
5000
Distance (ft)
Day 345
Day 355

Figure 36B

table decline, except that the pattern of water table differences between successive dates shows again that ditch recharge was operating for well AS1 and AS2 possibly also.

TIDAL HYDROPERIOD

Hydrographs from the tide gauges at Long Shoal River for August-December and Stumpy point for September-December are included as Appendix 13. The hydrographs for December are included here to illustrate the pattern of tidal variation (Figures 37 and 38). The tidal hydroperiod in Pamlico Sound exhibits three modes of variation. The monthly lunar variation is seen in the slight sinusoidal pattern of the hydrographs. The daily tidal fluctuation averages about 15-20 cm at Stumpy Point where there is a wide-mouthed bay opening to Pamlico Sound. At Long Shoal River, the daily tidal fluctuation averages about 25-30 cm where there is a narrow tidal creek connection to Pamlico Sound. However, the irregular wind tides can have a tremendous hydrologic impact on the DCR. Note the unusually high tidal influx followed by an unusually high tidal efflux on the last couple of days of December. The total water level change from high to low was about 1 m at the tide gauges. The high tide at Long Shoal River was sustained for more than 24 hours and resulted in flooding across the southern end of the DCR. These tidal effects were not noticed at the study blocks because the roadside ditches were well isolated from the tidal outlets by water control structures. However, these tidal effects influence ditch water levels for several kilometers up some outlet ditches that do not have control structures.

SOIL MOISTURE

The soil moisture samples were collected five days after the last rainfall event of 21 mm. There was significant variation in the water table depth across the blocks at the time of soil sampling. In Ash Block, the depth ranged from 54 cm at the north side of the block to 4 cm at the west end. In Waterfield block, the depth ranged from 40 cm at the east end to 6 cm at the west end (Appendix 8). The effects of location and depth of sample on soil moisture content were examined by comparing means (Tables 7 and 8). The effects of variation of water table depth on soil moisture were examined by graphing soil moisture versus water table depth (Figures 39-41). No statistical tests were conducted because of the small sample size.

The variation of litter moisture content is shown within microsites in Table 7 and across the blocks in Table 8. In Ash block, there was no variation among the surface litter samples collected in low areas versus those collected on the sides and tops of adjacent hummocks. In Waterfield block, the mean soil moisture of surface litter samples collected in the low areas was 133% compared to 113% for those from the sides of hummocks and 106% for those from the tops of hummocks. The means of litter moisture contents for all samples collected at the two wells at each of the quadrant locations in each block ranged from 93% at the south side of Ash block to 134% at the west end Ash block and the east end of Waterfield block. The high random variability of the sample moisture contents is shown in the relatively high standard deviations.

The graph of litter moisture content versus water table depth (Figure 39) shows that there was no consistent pattern of correlation. There was relatively wide variation of litter moisture content even for samples taken in the low areas where the water table was within 10 cm of the surface. Both zones of most shallow water table depth (west end of Ash block and west end and north side of Waterfield block) are also areas with significant hardwood component in the overstory.

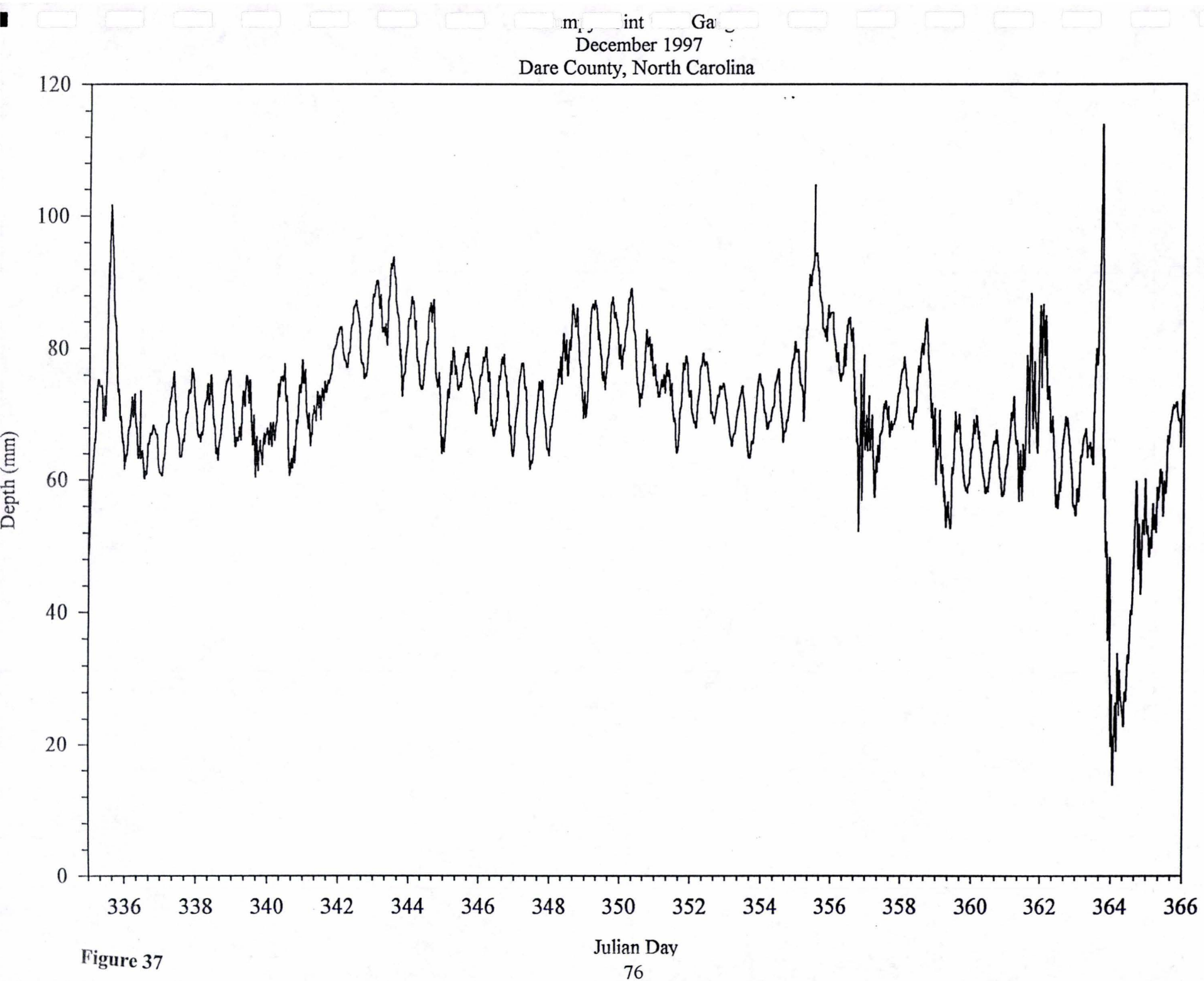
December 1997
Dare County, North Carolina
120
100
80
60
40
20
0
Depth (mm)
336
338
340
342
344
346
348
350
352
354
356
358
360
362
364
366
Julian Day

Figure 37

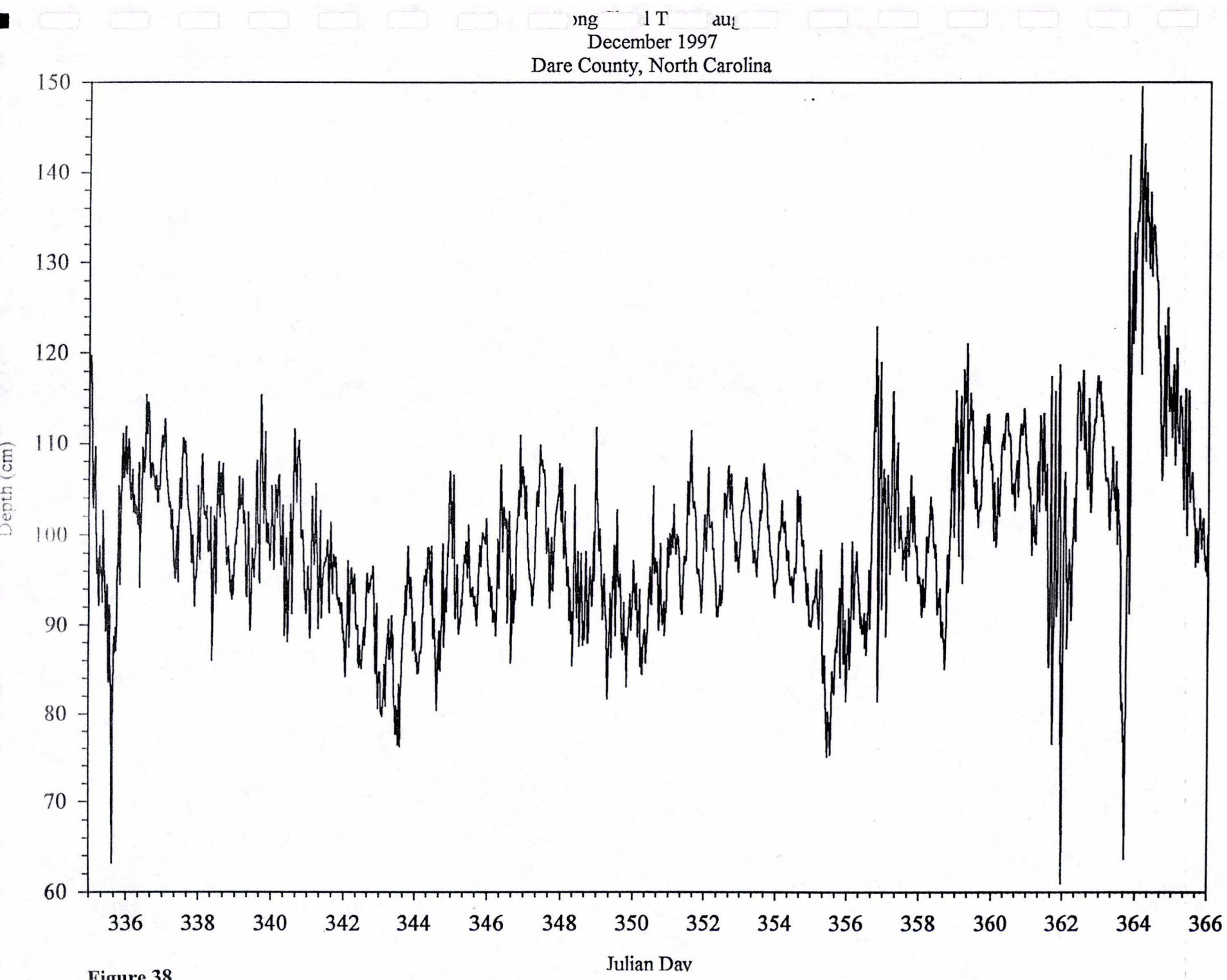
December 1997
Dare County, North Carolina
150
140
130
120
110
100
90
80
70
60
Depth (cm)
336
338
340
342
344
346
348
350
352
354
356
358
360
362
364
366
Julian Day

Figure 38

These zone, therefore, had more radiation input and wind movement at the surface than the pine dominated overstory throughout the remainder of the blocks.

Table 7. Microsite variation of soil moisture (% by weight) within blocks; means of eight samples *, standard deviation in parenthesis.

Sample Location	Ash Block	Waterfield Block	Mean of Both
a	114 (33)	133 (41)	123 (37)
af	322 (45)	366 (26)	344 (90)
m	285 (59)	502 (195)	394 (174)
b	115 (29)	113 (42)	114 (35)
bf	277(58)	264 (54)	270 (64)
c	114(30)	106 (36)	110 (31)
cf	252(33)	251 (33)	251 (43)

*Samples collected at wells 1 and 2 on each transect.

Note: a – surface of low area
af – fibric layer in low area
m – muck layer in low area
b – surface on side of hummock
bf – fibric layer on side of hummock
c – surface on top of hummock
cf – fibric layer on top of hummock

Table 8. Variation of soil moisture (% by weight) across Ash and Waterfield blocks by depth;

Location in Block	Litter	Fibric	Muck
Ash East	129 (27)	272 (54)	302 (27)
Ash West	135 (25)	267 (88)	328 (90)
Ash North	99 (12)	303 (35)	246 (1)
Ash South	93 (25)	293 (34)	266 (75)
Ash Mean	114 (28)	284 (55)	285 (57)
Waterfield East	134 (25)	244 (28)	469 (183)
Waterfield West	105 (49)	285 (141)	624 (132)
Waterfield North	126 (36)	373 (105)	636 (30)
Waterfield South	104 (46)	273 (20)	280 (152)
Waterfield Mean	117 (40)	294 (97)	502 (186)
Mean of Both	116 (34)	289 (78)	394 (174)

Note: Litter value is mean of 6 samples – a, b and c at wells 1 and 2.
Fibric value is mean of 6 samples – af, bf and cf at wells 1 and 2.
Muck value is mean of 2 samples – m at wells 1 and 2.

There was a more consistent pattern of variation of moisture content among the fibric samples than for the litter samples. The moisture content of the fibric layer in the low areas was considerably higher than on the sides and tops of the hummocks (Table 7) with means of 344%, 270%, and 251%, respectively. Variation of fibric moisture content across the blocks was

Litter Moisture vs. Water Table Depth
January 4, 1998
Dare County Bombing Range

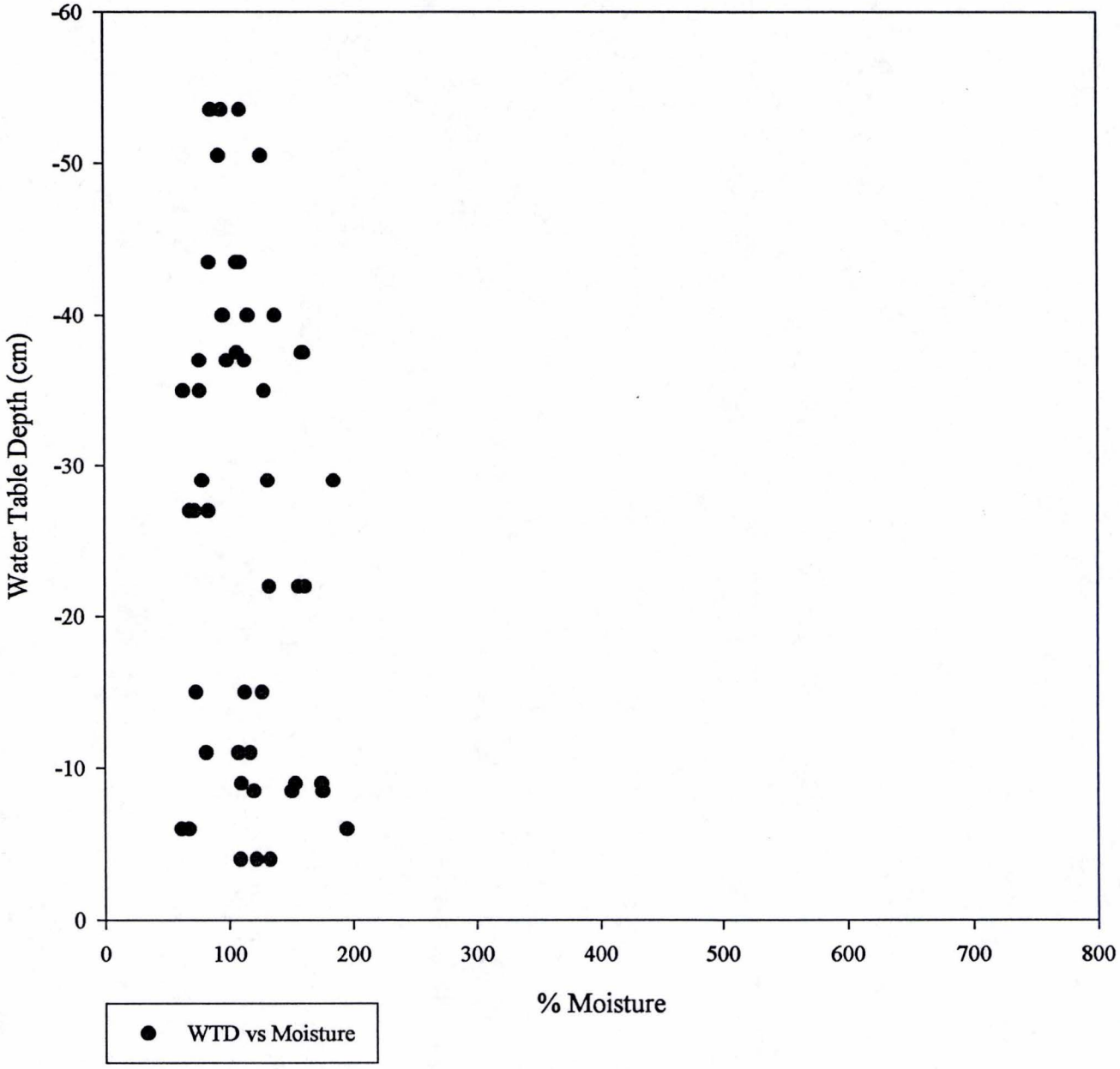

Figure 39

Fibric Moisture vs. Water Table Depth
January 4, 1998
Dare County Bombing Range

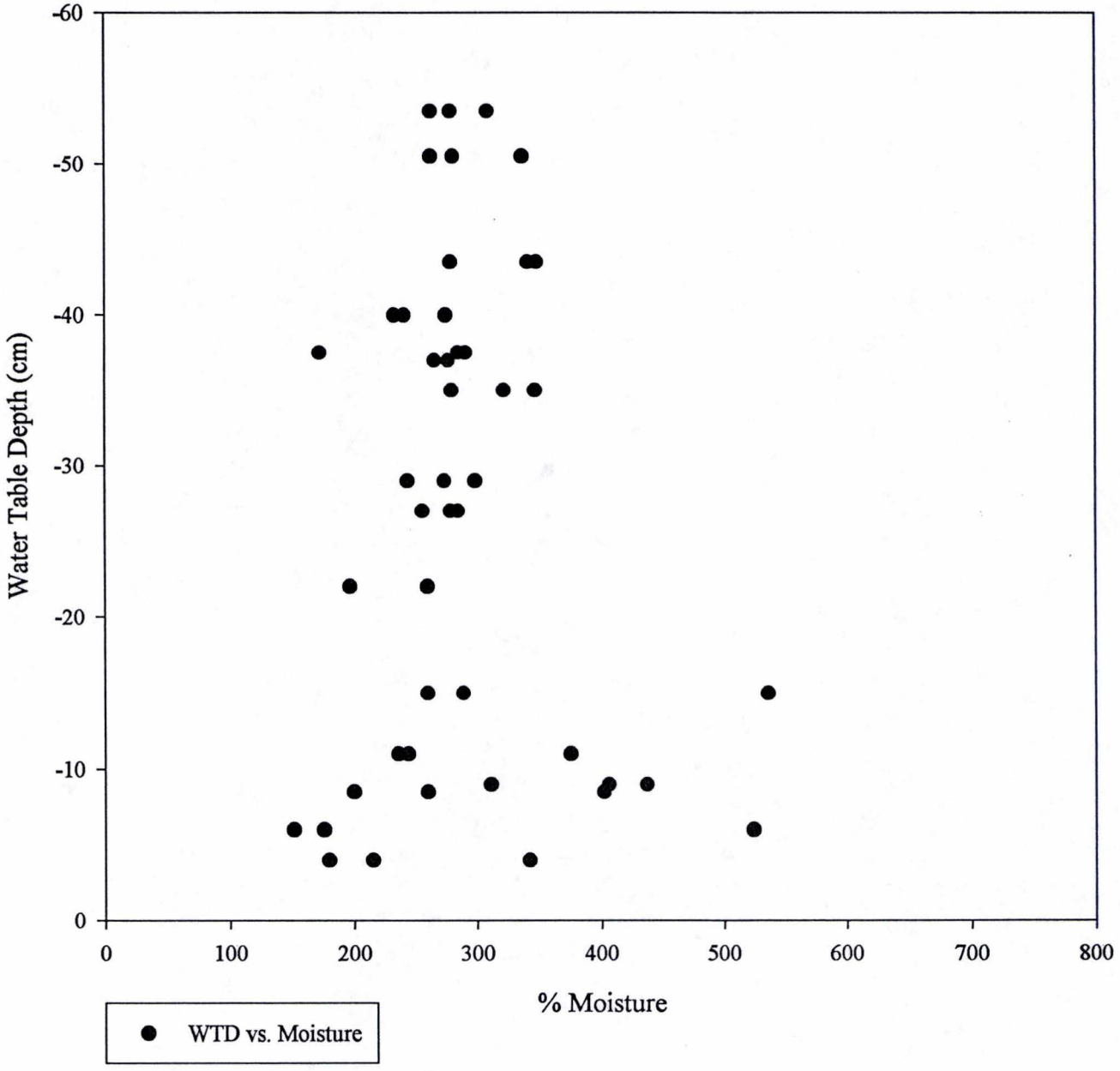

Figure 40

Muck moisture vs. Water Table Depth
January 4, 1998
Dare County Bombing Range

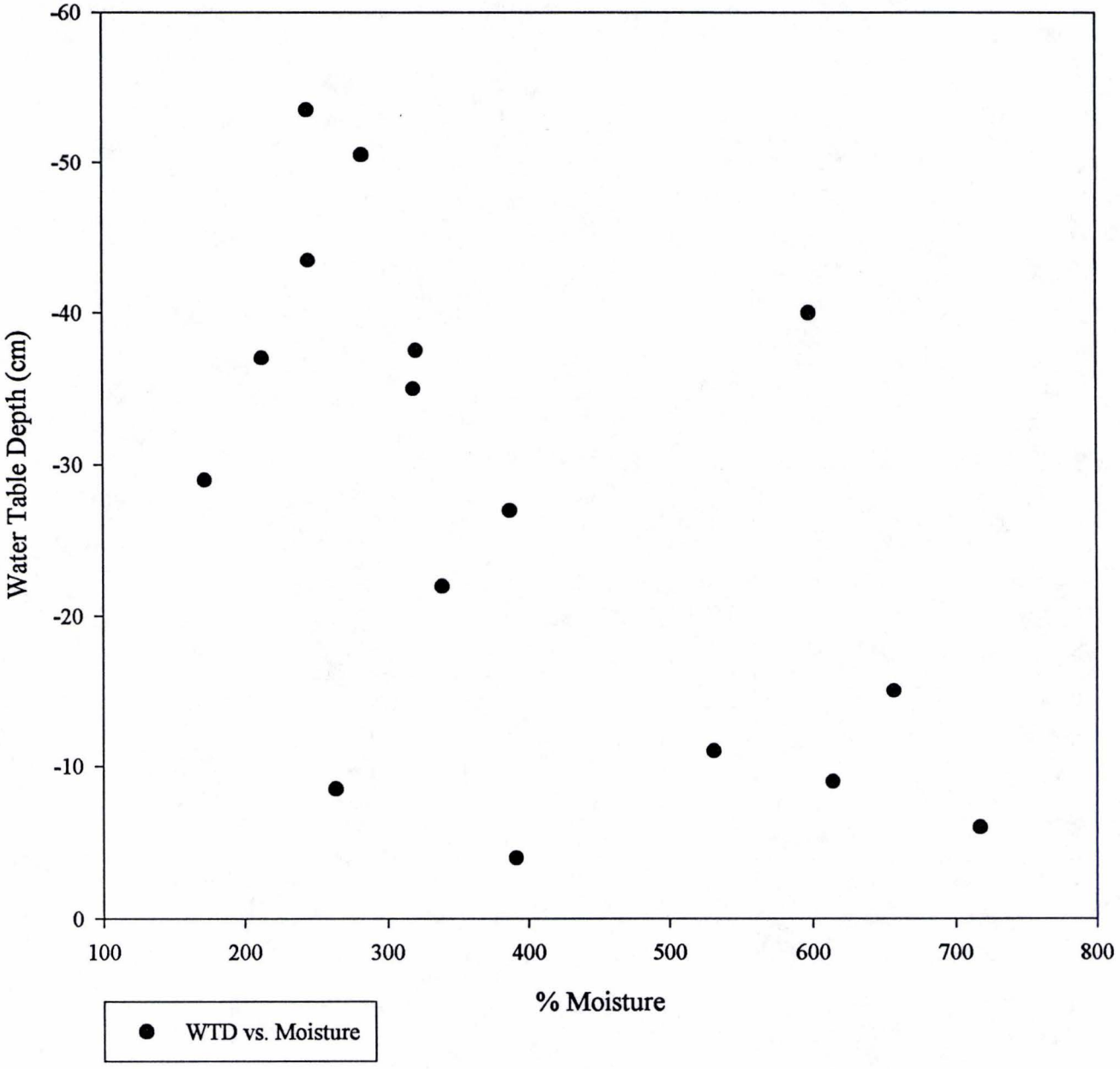

Figure 41

greatest within the Waterfield block, with means ranging from 244% at the east end to 373% at the north side. It is interesting to note that the highest standard deviation occurred in the zones where the water table was closest to the surface in both blocks. The graph of fibric soil moisture content versus water table depth shows a slight correlation, with all of the higher values at water table depths of 15 cm or less (Figure 40). The variation of fibric moisture contents at water tables depths ≤ 15 cm is reflective of the microsite variation. The higher values in that cluster are for samples from the low areas and the lower values are from the hummock tops.

As expected, the moisture content at the top of the muck layer varied considerably across the blocks and that variation was correlated with water table depth. The mean of muck moisture content at the quadrant locations varied from 246% at the north side of Ash block to 636% at the north side of Waterfield block. Within block variation was much smaller for Ash (246-328) than for Waterfield (280-636), reflecting the greater relief in Waterfield block. With only 16 samples, conducting a regression analysis was not appropriate. However, the graph of muck moisture content versus water table depth shows a correlation of decreasing muck moisture content with increasing water table depth, even though the variability is quite high (Figure 41).

PROPOSED WATER MANAGEMENT FEASIBILITY STUDY

Objective 5 of this study was to "Conduct pumping tests to determine the feasibility of water management strategies and the effects of water movement and storage on the water table level and soil moisture and ground level fuel moisture". A proposed work plan was drafted in June 1997 (Appendix 17) to guide a proposed pumping test to be conducted during mid-summer, 1997 while water in the road side ditches was still at moderate levels. Coordination of pumping equipment that belongs to the U.S. Air Force and to the N.C. Division of Forest Resources was effected. However, discussions with the U.S. Forest Service Contract Representative, Mr. Roger Hungerford, about the proposed tests led to a decision to postpone the tests until 1998. Mr. Hungerford felt that we had not collected enough data and developed enough information about the hydrology of the study blocks to make the pumping tests really useful and informative. Lack of continued funding into 1998, of course, precluded completing the pumping tests during that summer as planned.

At this point, knowledge and experience gained thus far in this project indicate that conducting a pumping test would not add significantly to our understanding of water management for prescribed burning. Pumping of water away from a block where a prescribed burn on organic soils is contemplated will not enhance water table control. There is ample evidence in the literature that the drainage effect due to lowering the water table in the ditches for a few days would be small. Achieving the optimal conditions of water table depth, muck moisture content, and ground fuel moisture content will be accomplished through the interaction of natural hydrologic factors. In particular, fire managers will need to us ET to lower the water table sufficiently to conduct an effective burn while maintaining enough water in the ditches to extinguish the fire. Pumping water will only be needed to quench a completed burn. Personnel of the NC Division of Forest Resources have ample experience in many different types of situations to successfully accomplish that task.

CONCLUSIONS AND RECOMMENDATIONS

The principal conclusions from this preliminary research relate to the hydrologic functions of the study site and the effects that those functions may have on water management planning for prescribed burning.

1. Because the 1997 rainfall was significantly below normal, particularly during late summer, the water table behavior described for the study site must be evaluated in light of that fact. The water table declined to much greater depths below the surface than normal in late summer and recharge was delayed compared to a normal year. Conducting a safe and effective prescribed fire on the study site during summer 1997 would not have been possible. However, in a summer with higher rainfall, the water table might rise close enough to the surface after a large rainfall event to facilitate the conduct of a burn.

2. The water balance on the study site was dominated by rainfall and ET. Runoff was nil for several reasons. Low hydraulic gradients across the site limit lateral surface or subsurface flow even when the upper fibric layer of the organic soil, that has a very high $K_{sat,}$ is saturated. When the water table is well below the fibric layer, very low K_{sat} in the muck and in the clayey mineral layer below the muck limits lateral flow. The clayey layer is somewhat restrictive and limits vertical percolation to the sandy sediments below it. The roads serve as dams to block lateral flow. Ditch outflow from the study area was limited by control structures in the vicinity of the Air Force impact zone. Ditch outflow from the study blocks is limited to flow southward in the Faircloth Road ditch and control structures limit outflow to Long Shoal River or to Whipping Creek.

3. The water table hydroperiod was influenced mainly by the interaction of rainfall and ET. The seasonal trend exhibited was a consistent decline of the water table during summer and early fall during the period in which PET consistently exceeded rainfall. Soil moisture recharge and increase in the water table level began when the ET rate began to decline in early October. The rate of water table decline was related to ET and rainfall and also was influenced by available water capacity of the soil, by local relief and by variations in ET related to variation in microtopography and stand character. Recharge of soil moisture from the ditches occurred by two different routes: positive gradient into the organic soil and positive gradient into the sand layer under the restrictive layer that resulted in recharge upward. It is important to reiterate that **the level of water in the ditches does not necessarily give any clue about the water table level in the adjacent stand.**

4. Variation in water table depth that would influence moisture levels in the organic fuel near the surface was related to several factors. Small surface gradients caused small gradients (about 20-30 cm) in water table depth across the study blocks. However, variation in water table depth and elevation of 20-50 cm occurred seemingly at random over very short distances. That is due to the microtopography of 0.3 – 1 + m, the variation in organic soil depth, and the microtopography of the mineral soil surface under the organic layer.

5. Water movement on the study sites is very limited and occurs very slowly in the horizontal direction. However, evidence shows that vertical preferential flow through the upper part of

the organic layer may be relatively rapid when a large rainfall event results in high water potential at the surface.

6. Soil moisture content was highly variable and related to microtopography and to the water table level. The moisture content of the litter was not related to topographic position or to the depth of the water table. The moisture content of the fibric layer was somewhat related to topographic position and the water table. The moisture content was lower for samples taken from the sides and tops of hummocks and was also slightly related to the water table depth when the water table was within 20 cm of the surface. The moisture content of the muck beneath the fibric layer exhibited relatively good correlation with water table depth.

Recommendations for hydrologic analysis of organic soil sites prior to planning and conducting a prescribed burn are outlined below.

1. The lessons learned in this study indicate that it is important for the manager to have a good understanding of the general hydrologic character of the site in question. That includes the basic stuff: soils, hydrography, topography (particularly the local and microtopography), and the character of the climatic normals. The possible windows of opportunity for conducting a prescribed burn can be analyzed with these readily available data.

2. It is recommended that water table data be collected for at least one year prior to planning a burn so that the entire seasonal trend of the hydroperiod can be studied. As this study has shown, there is no such thing as a "normal" climatic year and therefore no such thing as a normal hydrologic year. However, water table data is critical to understanding the variability that one can expect in the moisture content of the organic soil.

3. Taking some relative elevation measurements around the site prior to planning the installation of water table wells is important. Understanding the factors that will influence spatial variability in the water table depth will provide for cost-effective water table monitoring. On this study site, with our current knowledge, four wells placed about 300 m from the roads, one on each side of the block, would provide adequate information on the principal water table variation. A few additional wells might be placed on the obvious topographic highs and lows. Weekly manual measurements of the water table level provides adequate information on seasonal trends of the water table level. However, I recommend at least one water level recorder to capture those rapid water table rises that might create a short period when conducting a fire is feasible.

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